VOLUME 105 PART A NUMBER 19 FEBRUARY 1958

The Proceedings

OF

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PART A

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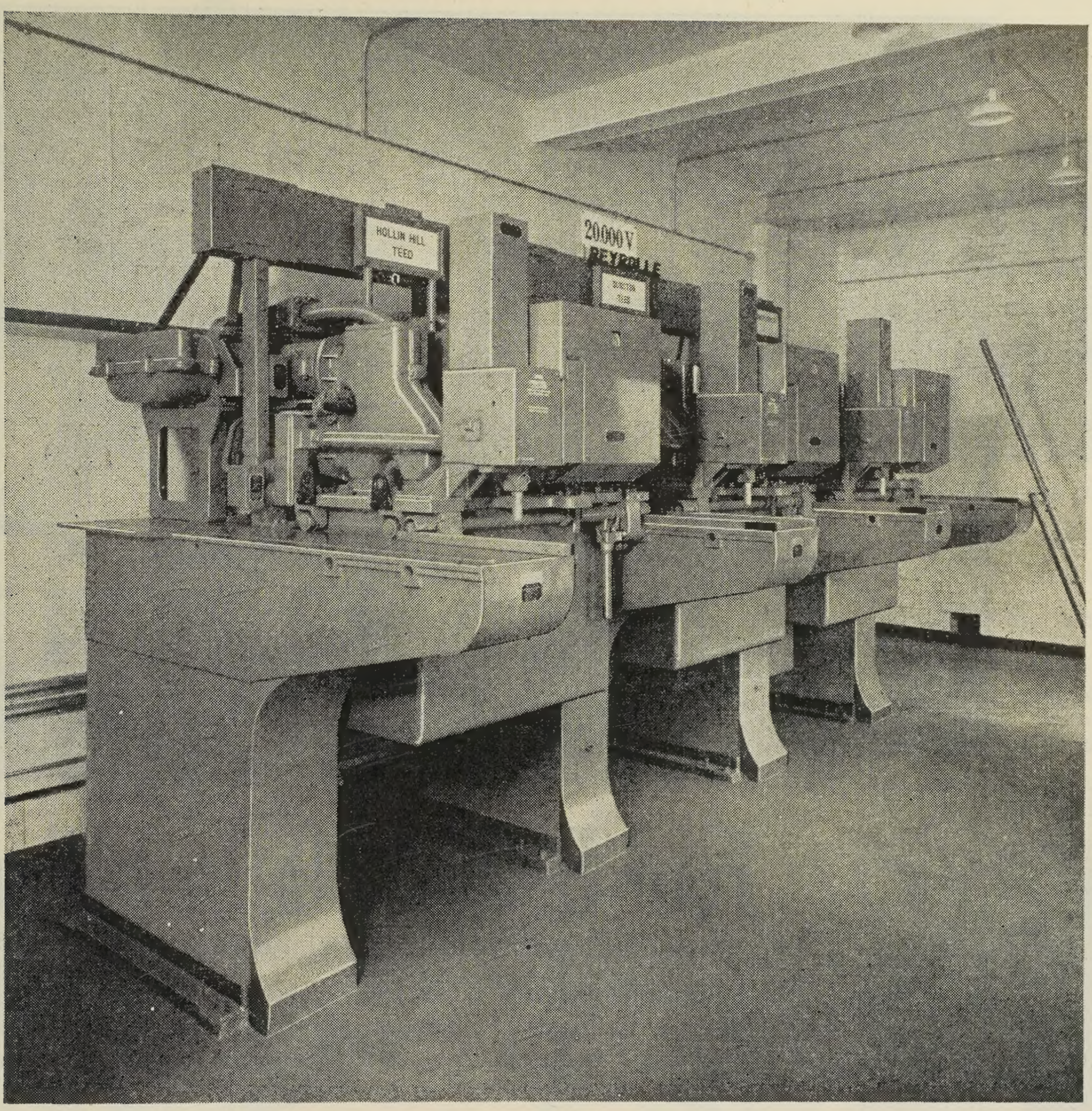

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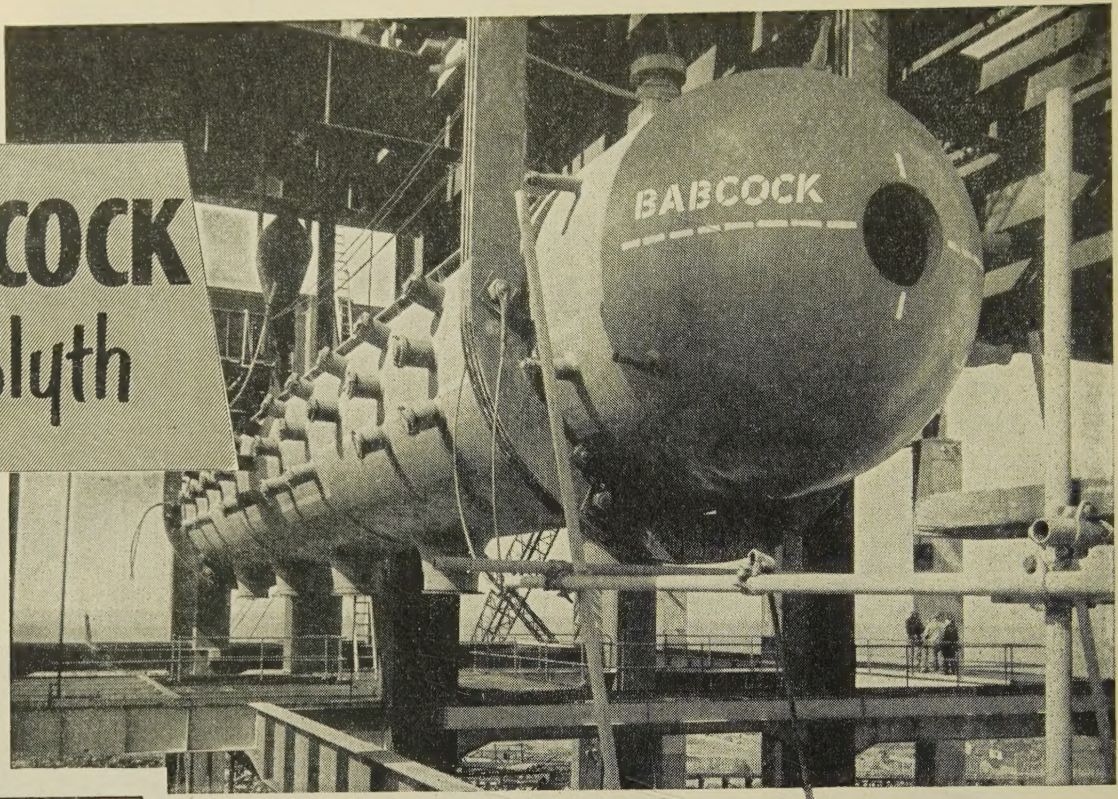

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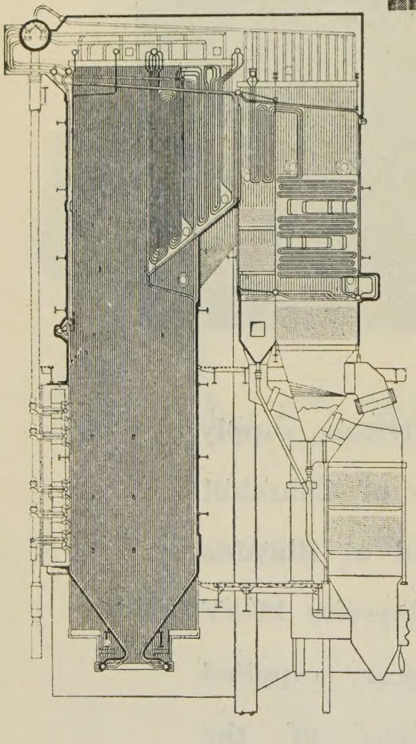

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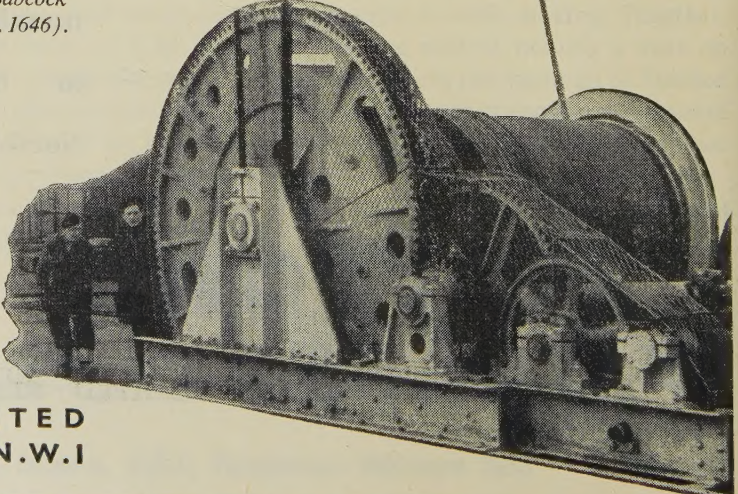

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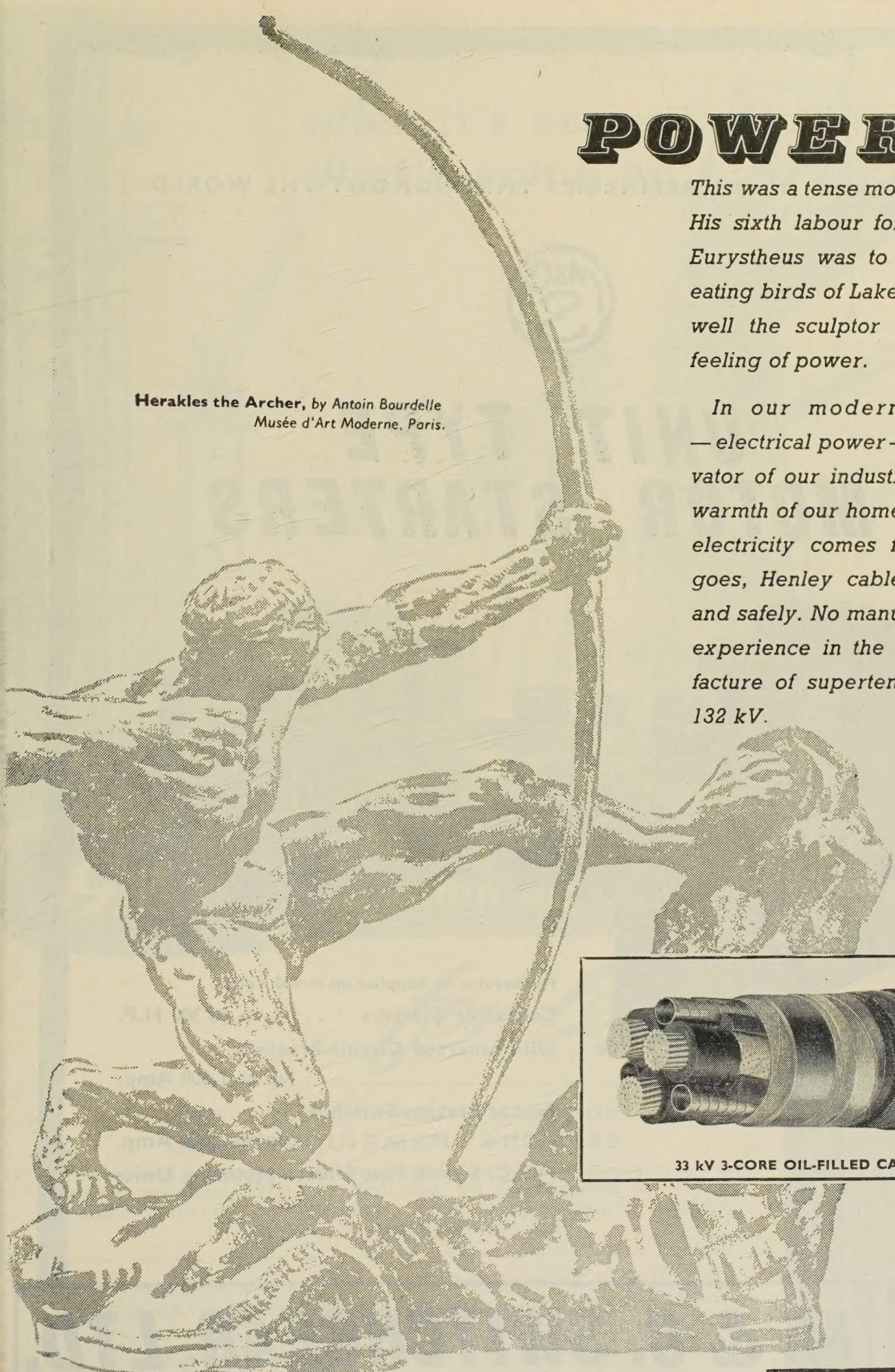

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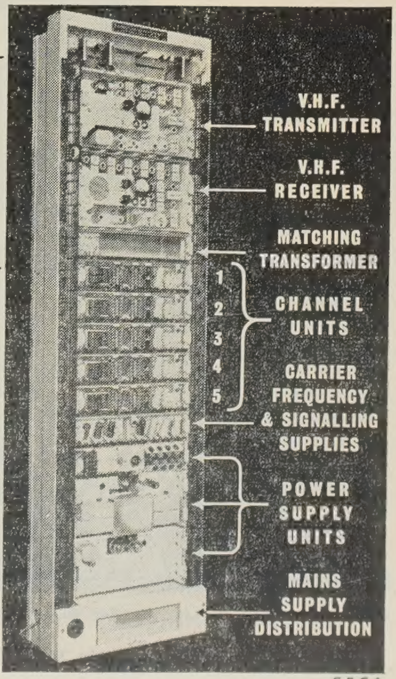

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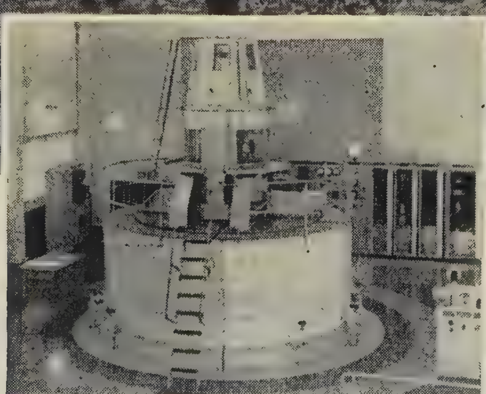

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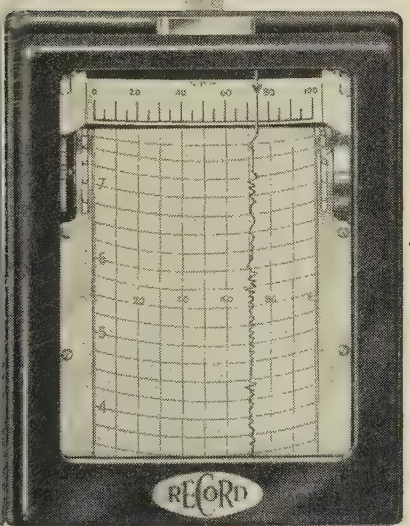

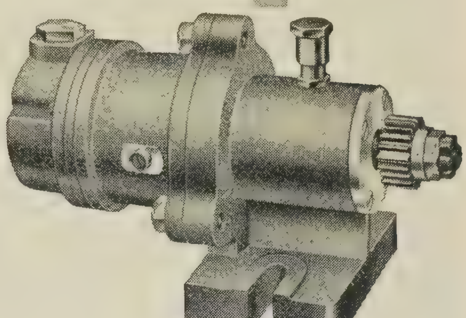

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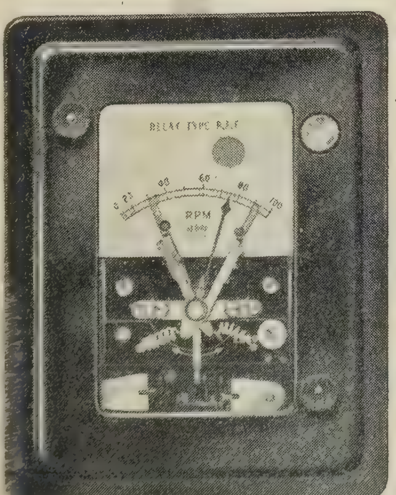

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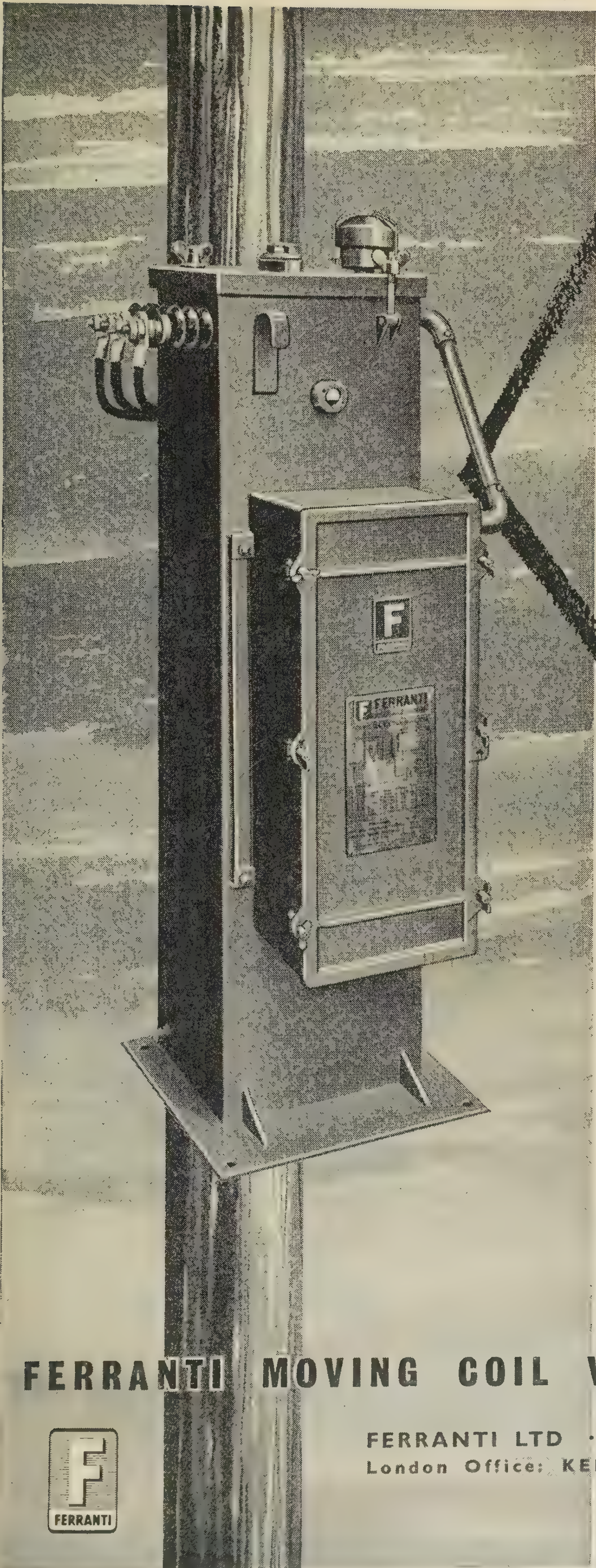

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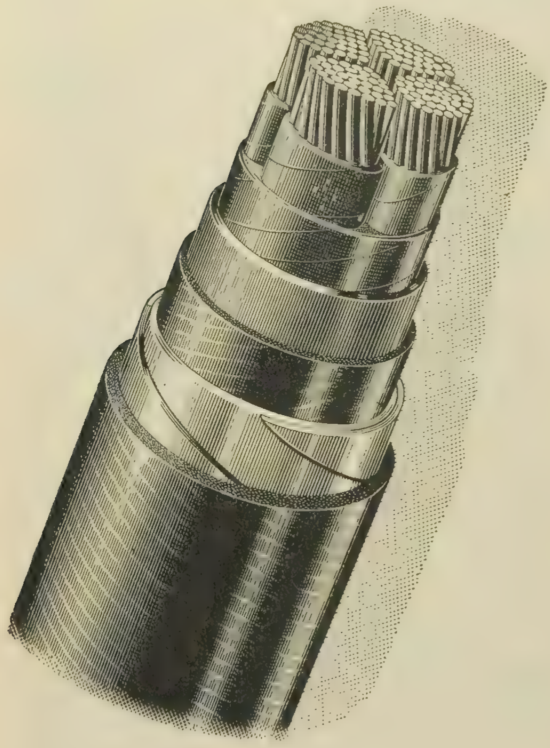

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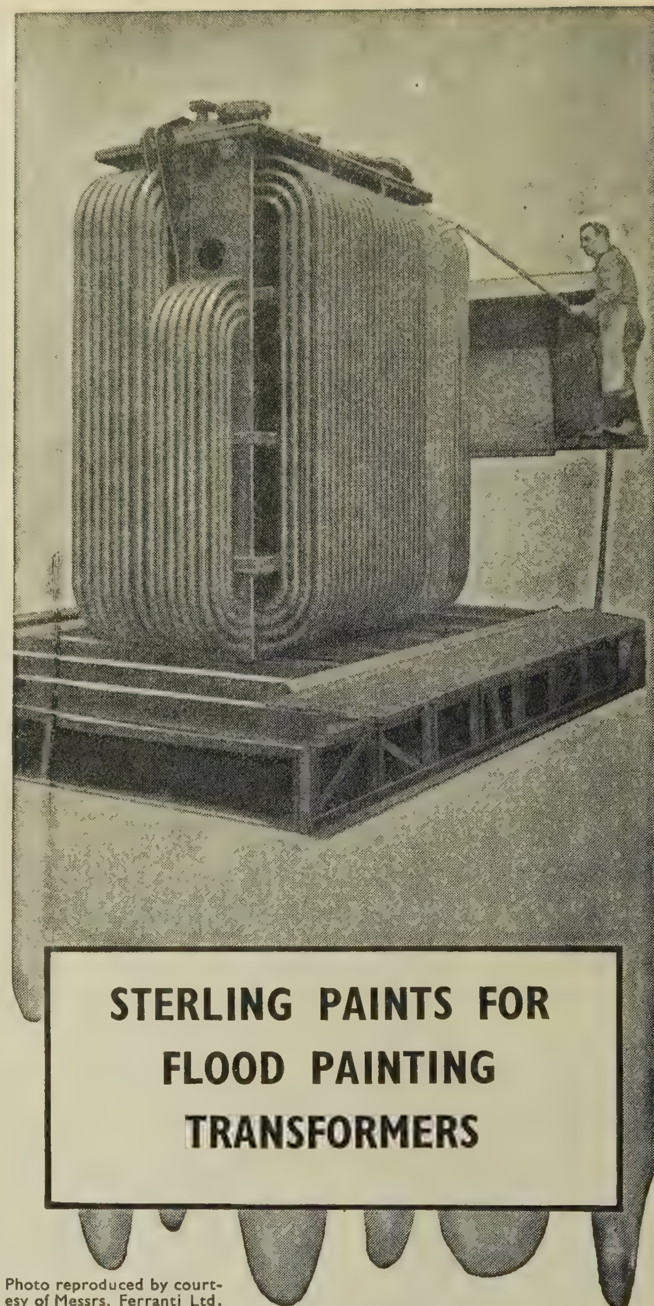

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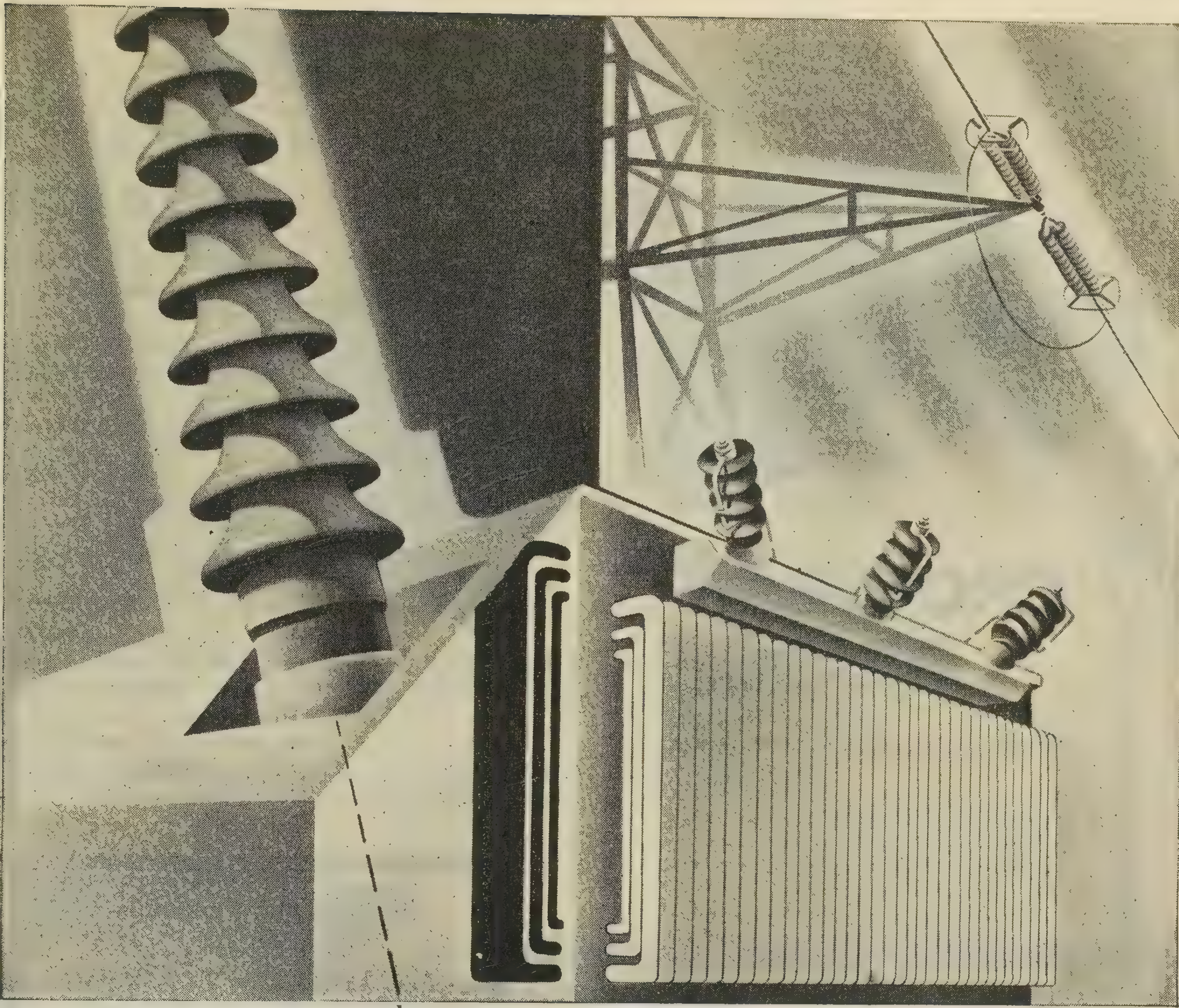

INDEX OF ADVERTISERS

THE PROCEEDINGS OF
THE INSTITUTION OF ELECTRICAL ENGINEERS

EDITED UNDER THE SUPERINTENDENCE OF W. K. BRASHER, C.B.E., M.A., M.I.E.E., SECRETARY

'OL. 105. PART A. No. 19. FEBRUARY 1958 ©

The Institution of Electrical Engineers
Paper No. 2436
Oct. 1957
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INAUGURAL ADDRESS

By T. E. GOLDUP, C.B.E., President.

BACKGROUND, FOREGROUND AND HORIZON

The Radio Valve Industry in Prospect and Retrospect

(*Address delivered before* THE INSTITUTION *3rd October*, 1957.)

To be elected President is the highest honour that can be onferred on a member of this great Institution, and it is an vent of extreme importance to those who are chosen by their ellow-members to serve in this capacity.

I am deeply appreciative of this honour, which I regard as a nost generous compliment, not only to me personally, but also o the light electrical engineering branch of the profession, and ndeed to the radio industry which I have served for so long. During my term of office the responsibilities I assume as your resident will be constantly in my thoughts as I strive to uphold ne high standard of service which has characterized the work f those distinguished electrical engineers who have occupied ne Presidential Chair in past years.

There is not one of us, I am sure, who does not look with pride n 1871 as the most significant year in the history of electrical ngineering, for in that year The Institution came into being nder its original title of 'The Society of Telegraph Engineers'. n recalling the state of science at that time, it is interesting to ote that it was in this same year that James Clerk Maxwell was ppointed the first Professor of Experimental Physics at Cambridge, where he propounded his theories of the electromagnetic ature of radiant energy, and founded the Cavendish Laboratory. Of the eight original founders of The Institution (five of whom ncidentally were members of the Armed Forces), together with ne sixty-six original members as recorded in the minutes of May, 1871, none could possibly have foreseen the ultimate nportance of The Institution as a national body, and certainly one could have contemplated the possibility that in less than century the members, numbering more than 40 000, would ave elected a President whose working life had been spent in a eld described to-day as light electrical engineering and on a ighly specialized subject, the threshold of which had not then een crossed. Such, however, is the scale of the time-base oncerned with the development of thermionic valves, the Golden Jubilee of which was celebrated in this lecture theatre in 954. Our founders certainly could not have imagined the npact of Fleming's or de Forest's work on the pattern of our ves to-day, where thermionic valves and a whole family of related devices have become an all-important factor in every branch of engineering and science—a factor which more than any other has not only shaped but determined the progress in electrical engineering as we know it to-day, and has in consequence profoundly influenced almost every other form of human endeavour.

It is with these thoughts that I embark upon the task of delivering this Address and in so doing I would first like to dwell for a moment on the significance of The Institution in our national life. Our Royal Charter requires us as an Institution 'to promote the general advancement of Electrical Science and Engineering and their applications, and to facilitate the exchange of information and ideas on those subjects amongst members of The Institution'.

The whole machinery of The Institution is devoted to this end, an important part being the work of the Local Centres and Sub-Centres, and the Oversea Branches and Joint Groups, constituting 64% of the total membership. The meetings and discussions which these Centres and Groups organize are devoted directly to the implementation of the terms of our Royal Charter.

We all appreciate the wisdom of our predecessors in providing these facilities, which have done so much to meet the needs of members in the provinces and oversea, as well as adding to the prestige of The Institution as a whole. But a good deal more is involved than the mere dissemination of information among our members and the promotion of electrical science and engineering, to say nothing of our responsibility as a body to ensure and maintain adequate professional standards. Important and necessary as all this is, in the ultimate it is the collective effort of individuals which matters, and each of us has a personal responsibility to ensure that his own individual contribution to the profession is adequate in all respects. That the total contribution is adequate is reflected in the pre-eminent position our Institution is proud to hold, but it is nevertheless the fact that this contribution comprises the strenuous efforts of only a relatively small number of members, and I would ask each of you to consider whether your individual contribution to The Institution and to

the development of the science in which you practise is as great as you feel it should be.

We must never forget that it is the responsibility of the coming generation of engineers to see that our present leadership is maintained. Their task in this respect will demand a recognition of the fact that these are days when the knowledge which is increasing rapidly in all fields of engineering and science must be matched with increased wisdom, for if these two fail to go hand in hand disaster will eventually overtake us. I appeal to the younger members of this Institution to mark well my words and ponder on the truth expressed in Proverbs viii. 11:

> For wisdom is better than rubies and all the things that may be desired are not to be compared to it.

Now I must turn from The Institution—the frame in which my Address is set—to the picture, the Address itself, and I shall sketch it on a broad canvas, my main theme being thermionic valves, a subject which has constituted my life's work, first for a few years in the sheltered atmosphere of an Admiralty research establishment and then for many years in the hard but exhilarating school of industry. I am anxious regarding the scope and length of my Address for I am faced with the difficult task of deciding the extent of the ground to be covered.

That the major part of my Address should have as its theme some aspect of thermionic valve development I was never in doubt, and it was my original intention to give a more or less complete review of valve developments. After much thought, however, it became increasingly obvious that to include the whole story would make this Address far too long. I then considered at some length those points of valve history which seemed to me most significant. But such is the nature of this field that I found I was merely repeating what had already been said and written elsewhere far more ably than I could attempt, and often in this very theatre. For these reasons and because I wish my Address to break new ground and perhaps leave you with some new lines of thought, I intend to confine what I have to say to a few aspects which I consider of interest and which are unlikely to be familiar to those of you who do not work in the valve field.

BACKGROUND

On the 16th November, 1954, The Institution celebrated the Jubilee of Ambrose Fleming's invention of the thermionic valve by a series of lectures and an exhibition. The proceedings of this memorable occasion, together with a catalogue of the exhibits, are recorded in an Institution publication entitled 'Thermionic Valves 1904–1954', which gives a good pictorial representation of the progress achieved since Fleming applied for his patent in 1904. This record embodies the whole family of thermionic valves, from simple diodes to the multi-electrode valves, and on to magnetrons, klystrons and travelling-wave tubes, all of which bear little resemblance to the fragile hand-made diode which Fleming used in his Gower Street laboratory for his early experiments.

With all new products an evolutionary streamlining process occurs in which new design ideas, new materials and new applications all combine to influence appearance, utility and efficiency to such an extent that the original design is barely recognizable. The thermionic valve is no exception, its present appearance bearing little resemblance to the electric lamp from which it is in many respects descended. Its first appearance in the form of a simple diode opened a field of progress in design, manufacture and application, the horizon of which is still a long way off.

Manufacture of valves in this country began during the years of the First World War, when a new industry developed, born of the vacuum techniques which were in common use in electric lamp manufacture. The somewhat limited output of both vacuum and gas-filled types, referred to in the jargon of those days as 'hard' and 'soft' valves, was used exclusively for the communication equipment then available to the Armed Forces. However, apart from some specialized applications in telephony, the valve output of the early 1920's was used for broadcast receivers, and it has been the subsequent development of sound broadcast services and later television which has provided the incentive for the development of the valve industry.

There is little point in commenting upon the numerous types of valves now available—the figure is nevertheless somewhat staggering, as is also the multitude of applications that are covered. From the early days of manufacture there has been a relentless and continuous attack on valve design and manufacturing problems in an endeavour to meet the seemingly endless demands of existing and new applications which have become characteristic of the advance in the ever-widening field of electronics. As a result we now have thermionic devices of every conceivable type, from the conventional receiving and transmitting valves to their more complex counterparts for use at the highest frequencies; also counting, storage, display and infra-red devices, and the transistors that have emerged from the study of solid-state physics.

The progress achieved is an example of combined operations on a number of technical fronts, involving the physicist, the chemist and the metallurgist, as well as the electrical and the mechanical engineer. By this consortium of effort, the design, manufacturing and application problems have been tackled and solved. In reviewing the highly satisfactory results that have been achieved it is, strangely enough, most difficult to highlight specific technological achievements; so far as manufacturing technology is concerned there has been an advance on the broad fronts of chemical and mechanical engineering, combined with a strict control of raw materials and processes. The introduction of new and more suitable materials and the rigid adherence to manufacturing schedules have also contributed to the development of new and improved thermionic devices.

FOREGROUND—PLANT AND PRODUCTION

The following is a brief description of one or two production processes, intended to give some idea of the materials from which valves are made, their various component parts and how they are assembled.

Taking as an example an indirectly heated h.f. pentode, the cathode consists of a flat nickel tube which is coated with a mixture of barium and strontium carbonates 80 microns thick. When the valve is heated during the pumping process these carbonates are converted to oxides, and final processing produces a small amount of free barium and strontium, without which the emitter would not function. In addition, the valve design must be such that the emissive coating is not damaged by the heat applied to the valve envelope and electrodes during sealing and exhausting.

The heater, which fits inside the cathode, is made of tungsten wire 70 microns in diameter, drawn to an accuracy of $\pm 0{\cdot}7$ micron. Its operating current is 300 mA and it works at 1200° C.

The molybdenum wire used for the grids has a tolerance of $\pm 1\frac{1}{2}\%$ on diameter. The grid-pitch tolerance is ± 1 micron, and this accuracy must remain after the grids have passed through a cleaning process where they are heated in an atmosphere of hydrogen at 900° C.

Finally, these electrodes and the anode are assembled between two mica discs, which must locate them to an accuracy of 20 microns; after assembly the distance between the electrodes is nowhere more than half a millimetre.

The production of glass parts is of great importance in valve ıd cathode-ray-tube manufacture. The need for accurate mensions and uniform composition requires a detailed applica-on of glass technology. Glass tubing, in one application, is sed for cathode-ray-tube necks, the tube being flared at one end fit the cathode-ray-tube cone. This flaring is done at a mperature of 800° C and at a rate of four per minute. In nother application, to valve envelopes, a tube is closed at one ıd in a mould at a temperature of 1 050° C.

In another process the face of a television tube is joined to the one. The glass is some ⅝ in thick to withstand atmospheric essure when the tube is evacuated, and in order to establish the aling temperature uniformly across this width, after the glass as first been heated by gas flames, a current is passed through , taking advantage of the property of glass whereby its electrical sistance is relatively low at high temperatures.

While a vacuum device is being exhausted the glass and ectrodes are heated so that any absorbed gases are driven off. or instance, a large cathode-ray tube passes through a heated nnel during a period of some two hours; in the case of receiving lves this process is carried out in a few minutes on much naller machinery of an entirely different design. This demon-rates the range of techniques employed in a single process.

While many production processes are done mainly or wholly machine, a great deal of work is carried out by semi-skilled perators. Here the technique of operator training replaces to large extent the technique of production machinery design, nd correct selection and training methods are just as important accurate know-how and technology. Methods of operator aining are always being given considerable thought, but we ave still quite a lot to learn.

The foregoing will, I hope, serve as an example of the combined forts of mechanical, chemical and electrical engineering plus me applied physics, metallurgy and glass technology, all o-ordinated in the interest of efficient mass production of ermionic valves and kindred devices.

I included this account to illustrate the part that plant design ıd development has played in the manufacture of valves. It a subject which seldom appears in papers read before The stitution, and for very good reasons, but this in no way inimizes its importance.

Research and development have their own special appeal and e a distinctive and satisfying element in the achievement of sults which thrive on differences of approach to the solution problems. The same is equally true of plant design and evelopment, and, as a stage in the chain of events leading to a anufactured article, their importance is paramount, for they e prime factors in the economics of production. In this onnection it is as well to remember that only by economic and ficient production can industry continue to exist and provide e necessary finance for research and development, and indeed r all its other activities. Additionally, plant design determines ery largely the actual manufacturing processes to be used and what extent it is possible to employ modern technological lvances.

The design problems of radio valves and for that matter of ıy thermionic device are, as in the case of most products, timately linked with the manufacturing possibilities, which in rn are mainly dictated by the capabilities of the plant and its esigners.

New techniques are constantly being introduced, a recent novation being the working of metals by electro-sparking volving an electric erosion effect. This enables holes of the ost complex shape to be cut in the hardest metals by unskilled bour. An electrode, which can be of brass or steel, is first ade to the shape and size of the hole required, and by passing an electric discharge through a liquid dielectric medium between this electrode and the workpiece, a hole is cut corresponding to the outline of the electrode. This hole, cut to very close limits, is extremely smooth, the workpiece produced being suitable for incorporation in, say, a punch tool without any further finishing. Flame-plating is another technique with great possibilities which, by the use of very high temperatures and pressure, enables tungsten carbide to be plated on a great variety of metals, including steel, cast iron, aluminium, copper and brass. This enables a part to be produced with an extremely hard surface, but retaining the metallurgical properties of the base metal. Aluminium oxide can also be plated on by this process, producing a surface highly resistant to chemical attack, and able to withstand high temperature.

Like so many other developments in the electronics industry, plant construction is almost entirely a matter of mechanical engineering, as Figs. 1 and 2 illustrate. Looking at the achievements since valve manufacture started after the First World War, I regard factory plant design as the hub from which have stemmed improvements in productivity, quality and quantity, the introduction of modern technological processes and the inspiration for achieving the almost impossible in the complex chemical and vacuum processes that are involved.

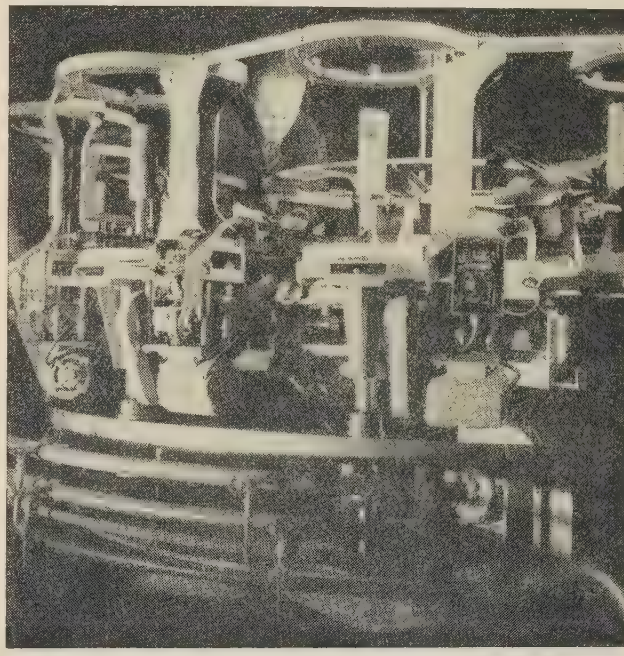

Fig. 1.—Constructing a 12-head cathode-ray-tube sealing machine.

The extent and nature of plant design and development problems are well illustrated by the fact that the tendency has been towards miniaturization in receiving and other valves, while the exact opposite is the situation with cathode-ray tubes. With the advent of the transistor, still smaller products have had to be manufactured, as shown in Fig. 3. The mere mechanical handling, during the various manufacturing processes, of these extremes in size is of itself a major engineering design problem, requiring in each case a quite different approach and a vastly different type of mechanism. Incidentally, added complications in cathode-ray-tube manufacture are the change from a circular- to a rectangular-faced tube and the introduction of metal backing of the luminescent screen.

However, these are not the only factors to consider in the design of production machinery, for, as already mentioned,

Fig. 2.—Setting up a 24-head turret in preparation for boring the indexing holes to an accuracy of 1/10 000 in.

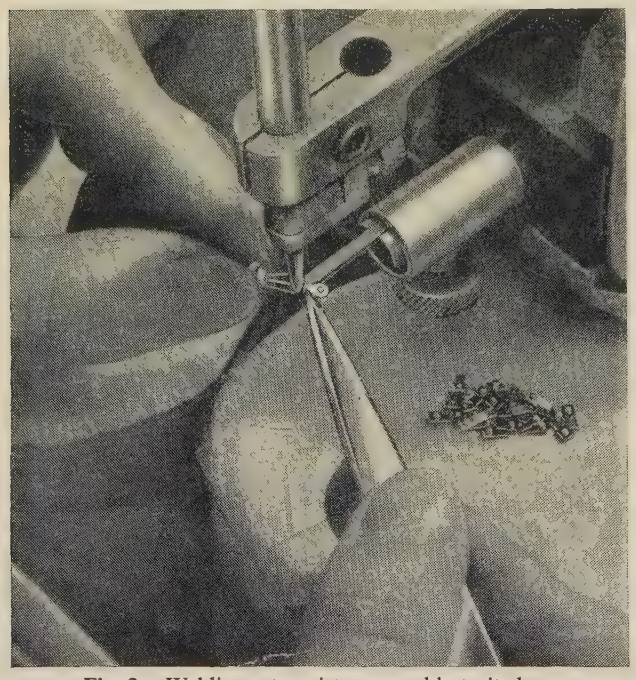

Fig. 3.—Welding a transistor assembly to its base.

manufacture involves the preparation of a vast number of different types of wires, electrodes, mica distance-pieces and glass tubing in various forms, all made to quite small tolerances, chemically cleaned and ready for assembly to form a complete valve which will eventually be exhausted, sealed and tested. Of major importance is the co-ordination of all the various pieces of plant in regard to speed and output, the avoidance of unbalanced stocks at any given stage in the manufacturing processes, and a smooth, unhindered, flow during the whole course of manufacture. Finally, it is in the nature of any vacuum device that, once made, it is impossible to alter its internal structure, which determines its characteristics, should it fall below the test specification or in any other way give an inferior performance in practice.

It will be of interest to consider the magnitude of this relatively new industry. In 1956 the turnover of the British valve industry was £25 million, and it produced 64 million valves of all types and over 2 million cathode-ray tubes, for radio and television, radar, communication, export, industrial applications, and to meet Government and Service needs. Additionally, a large number of the more specialized vacuum devices were supplied to various users for television cameras, X-ray equipment and instrumentation for nucleonic control. The corresponding numbers for 1949 were 19 million valves and 310 000 cathode-ray tubes, and this comparison gives a measure of the expansion of the industry in the post-war years. The relative expansion since 1930 is shown in Fig. 4.

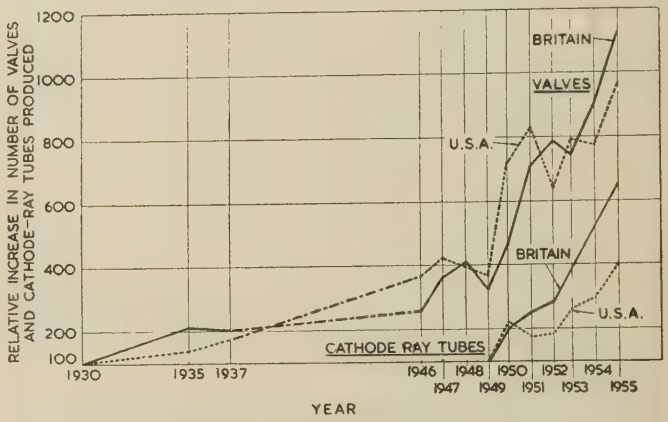

Fig. 4.—Growth of valve and cathode-ray-tube production in Great Britain and the United States.

It is difficult to obtain exact figures for the whole electronics industry, but those available suggest the impressive total of £300 million turnover for 1956, divided between professional equipment, entertainment equipment and vacuum devices as follows:

1. Government, industrial, communication, export (excluding valves):	%	%
Complete equipments	53	
Loose components	8½	61½
2. Entertainment equipment (excluding valves)		30
3. Valves—i.e. transmitting and receiving valves, cathode-ray tubes, thyratrons, photo-electric cells and other vacuum devices		8½
		100

It is significant that professional equipment accounted for a larger share of the total than entertainment items—a trend which will surely continue.

It is always interesting to compare the British and American valve industries. In the year 1956, measured in terms of receiving-valve output, the American valve industry was a little more than seven times as large as our own, produced 5½% of total United States industrial production, and accounted for 67% of the world production of 743 million valves; the British valve industry contributed 4½% of total United Kingdom industrial production and accounted for 9% of world valve production. Fig. 4 shows that the rates of increase of the American and British valve industries are remarkably similar.

There is no doubt that the general trend towards increased production will continue. Looking into the future we have to take into account the manufacture of transistors, which has now commenced here and in other countries, and which will continue

t a rapidly increasing rate. I estimate that by 1960 the world roduction of valves and transistors will possibly reach a total f 1 000 million.

THE CHANGING SCENE—NEW DEVELOPMENTS

Change has been the essence of valve development from the me of Fleming's early work, and as our knowledge of electron mission, vacuum techniques, circuits, and so forth, has expanded, o has the thermionic valve become increasingly a device of lmost limitless scope opening up an ever-widening horizon of pplication possibilities.

It is obvious, therefore, that a great volume of research and evelopment has always been undertaken in the valve industry, nd as I cannot possibly mention more than a small fraction of ne whole, I have limited my remarks to a few specific items. It vould be inappropriate in this Address to become involved in etailed technical considerations of these developments, for, like ll aspects of electronic science and engineering, the technical vork involved is of quite a specialist nature, and they are ssentially subjects standing in their own right.

Co-ordination of Valve Development

I will first refer to microwave valves, special-quality valves and emi-conductors; as evidence of the importance of these, during 947–56 over 100 articles were published on valve reliability nd hundreds on transistors, and in the spring of 1958 The nstitution is to hold an International Convention on Microwave alves, lasting several days. The reason I have chosen these nree is the interest displayed in them by the Government, for ational needs, through the agency of the Inter-Services Com-nittee for the Co-ordination of Valve Development (C.V.D.). ery wisely, arrangements were made during the war, and have ontinued ever since, to set up under the auspices of the Royal Naval Scientific Service of the Admiralty a department which as become known as C.V.D., to foster and take the responsi-ility for valve developments for applications in equipment used y the Armed Forces and to make sure that the various Services hould not be competing for limited technical resources in the alve industry. Since that time the C.V.D. organization and ffort has grown rapidly, and even since the end of the war the ffort applied by industry to Service needs has increased very aany times. The present C.V.D. expenditure on development ontracts must amount to a few million pounds per annum.

Besides placing development contracts, C.V.D. organizes ffective liaison with the valve industry and maintains close ouch with development results, and has built up a balanced attern of development projects, the sum total of which has dded considerably to our general knowledge of the three fields o which I have referred.

C.V.D. sponsorship of these projects has undoubtedly been a aajor contributing factor in keeping this country in the van of rogress, and the foresight of the Government in setting up C.V.D. has paid handsome dividends, fully justifying the steps aat were taken. The present occasion is an appropriate one n which to record the valve industry's appreciation of the work f C.V.D. and its personnel, and I would particularly like to take his opportunity of recording the contribution made by Sir rederick Brundrett. He it was who, in the early 1930's while t Signal School, an Admiralty radio research establishment, aw the necessity of inter-Service co-ordination of valve develop-aents, linked with the valve industry. It was from this con-eption that C.V.D. evolved and became one of the finest xamples of inter-Service and industrial co-operation during the ar and since.

Microwave Valves

Turning now to microwave valve development, a requirement of some importance is the availability of cathodes having extremely high emission current-densities, and a good deal of work has been directed towards the solution of this problem. As a result, some novel forms of cathode have appeared, one example being the dispenser type pioneered by Lemmens, where the emissive materials percolate to the surface of a porous tungsten body when the cathode is heated. This development has materially assisted the progress of microwave valve design towards meeting the ever-increasing demands for higher frequencies and powers.

Magnetron developments derived great impetus from military requirements for high pulse powers in radar systems. Initially conceived in this country by Randall, Boot and Sayers at Birmingham University, this device was rapidly taken up by America and became the subject of intense study. The main application for magnetrons is still in pulse radar and to a large extent will remain so, although some types of radar are likely to forsake the magnetron for devices such as the klystron or the travelling-wave tube.

In recent years the magnetron has made possible many new advances in conventional radar systems. The success of the British marine radar manufacturers in supplying the major part of the world's demand is well known, and becoming more common is civil-aircraft airborne radar for cloud and collision warning sets. The availability of magnetrons operating on wavelengths of a few millimetres has made feasible the radar control of ground movements on airport runways. Although radar using the pulse magnetron is considered to be rather old-fashioned, there is still a great deal of scope for expansion; in particular, one would expect to see magnetrons developed for still shorter wavelengths to provide greater resolving power for radar sets in cases where range is not important.

Apart from radar applications the magnetron has been extensively used as a source of radio-frequency power for linear accelerators. These instruments, in which electrons are acceler-ated to high energies, were initially developed as an atomic energy research tool and were then used for medical, radio-therapy and X-ray purposes. They now fulfil an important application in industrial processes connected with plastics. An example of this is the irradiation of polyethylene to increase its heat-resisting properties. The electrical industry is indeed indebted to the plastics industry for some of the modern advances in insulating materials, and the use of linear accelerators is, as it were, something given in return.

A limited application for magnetrons is as a source of power for radio-frequency cookers, and we may well see this gaining favour in the future. Food either pre-cooked or raw is placed in the 'oven' and subjected to strong microwave radiation, so being heated or cooked extremely rapidly by dielectric loss. The cost involved, however, may for the moment exclude its domestic use, but large caterers may favour the idea and use such a system.

The klystron was developed in its reflex form as a local oscilla-tor for superheterodyne receivers, and although the original ideas were American, a great deal of work was initiated in this country during the war, the contribution of Sutton and his team at Bristol and the effort at the Clarendon Laboratory being well known. Of late many improvements have been made in reflex klystrons in regard to ruggedness, reliability, life, and use at higher fre-quencies. Types have already evolved operating at wavelengths of 2 or 3 mm.

In the past the amplifier klystron received little attention because the magnetron produced radio-frequency powers with greater electronic efficiency and in return for far less development effort. Now, however, the situation is changing with the intro-

duction of phase-coherent radar, where the reflected pulse from a target is compared in phase with that which was transmitted, the resulting beat frequency being a measure of the target velocity. A fixed object will produce a zero beat in a phase-coherent system, and this identifying feature enables permanent echoes to be eliminated from the display screen. In addition, one can measure with great accuracy and instantaneously the velocity of a target—a point of considerable interest in any navigational problem, military or civilian.

There are many different variants of the phase-coherent radar system, an important common factor being the need for improved microwave amplifying valves, with the result that in this field work is being directed towards larger powers, higher efficiencies and increased bandwidths. Pulse powers of the order of megawatts are now possible and, in the lower-power types, gains in excess of 100 dB have been achieved. But by no means are all the answers known. Active research continues in the field of multi-cavity klystrons, where the problems are largely fundamental, involving the formation and maintenance of electron beams of very high current density. In slightly different applications the amplifier klystron has recently come into extensive use in navigational aids and in television broadcasting in Bands IV and V.

The travelling-wave tube was a most significant war-time invention, first conceived by Kompfner while working for the Admiralty. Kompfner's work showed that when a wave was travelling slowly along a structure such as a helix, a beam of electrons travelling at almost the same velocity and in close proximity to the wave would interact with it and amplify it, the extra energy in the amplified wave being derived from the kinetic energy of the electrons which are slowed down in the process. An important feature of the travelling-wave tube is the fact that, by special treatment of the electron beam after it leaves the cathode, the noise due to random velocity and density of the electrons can be largely removed, thus giving tubes with low noise factors which are particularly suitable for use as signal amplifiers.

The travelling-wave tube has received concentrated attention during the post-war years because the high gains and broad bandwidths obtainable make it ideally suited for use in centimetric wavebands for radio relays. The use of these wavebands has been necessitated by the big increase in the volume of traffic in telegraphy, telephony and television; for instance, the last named utilizes a bandwidth which could accommodate a thousand telephone conversations. The world's first radio relay using a travelling-wave tube was set up by the Post Office early in 1952 between Manchester and Kirk o'Shotts, since when complete ranges of tubes are becoming available for use in the programme for radio relays mentioned by Sir Gordon Radley in his Presidential Address of 1956.

Travelling-wave tubes are not necessarily limited to the few watts of power required in communication. Studies at really high power levels are progressing, and it may be that these tubes will become serious competitors of the amplifier klystron, for they are less complicated in many respects, having no tuned cavities and a simple magnetic focusing system. I believe that, in the long term, some communication will be carried out by the propagation of millimetric wavelengths along small-diameter waveguides. The possibility has already been demonstrated over fairly long distances, but many details remain to be worked out in connection with the actual propagation. In the meantime the valve industry realizes that the successful development of such a scheme is dependent upon the provision of practical oscillator and amplifier tubes, on which work is already proceeding, together with the more difficult and fascinating problem of miniaturization.

Backward-wave oscillators and amplifiers are particular forms of travelling-wave tubes having the advantage that they can be tuned by merely changing the anode voltage. It is difficult to see what the application of backward-wave oscillators will be, but apart from certain military possibilities one can imagine them eventually replacing the klystron as a local oscillator.

The International Convention on Microwave Valves will be of considerable importance in placing on record the huge volume of work that has been achieved in this field, not only here but in other countries. The gap in the spectrum between electromagnetic waves and infra-red radiation is closing, and how far this is so may be revealed in some of the papers to be presented.

Special-Quality Valves

During the period between the two world wars the urge for improvements in valve quality, performance and reliability resulted largely from the demands of the broadcast receiver manufacturers, and fruitful collaboration between them and the valve designers determined to quite a considerable extent the direction and scope of valve development. As a result, with the arrival of different applications, such as communication and airborne radar, the valves incorporated in them initially were those based on the design requirements of the domestic market. Such valves, however, were not primarily intended to withstand the shock and vibration associated with these new applications, so that there arose a need for a series of valves whose characteristics would not be impaired, nor their life shortened, by these more arduous conditions. The valve manufacturers, with the support of C.V.D., set to work to design valves to meet these new requirements, and found it necessary to study the properties of materials, the fatigue behaviour of glass, metal and mica, the influence of static stresses within the valve, the effect of cyclic stresses applied externally, the causes of gradual deterioration of electrical properties of the valve, and finally to review critically existing manufacturing methods. All this, and the development of sub-miniature types for missile work, has added greatly to our general knowledge of valve-manufacturing technology, the result being that several types of special-quality valves are now available, produced in air-conditioned plants under conditions similar to those obtaining in the manufacture of pharmaceutical products.

Semi-Conductors

The transistor was invented in 1948 at the Bell Telephone Laboratories in America during a study of the effect of external fields on the conductivity of semi-conductors. The first transistor was a point-contact type, but theoretical considerations soon showed that the principles could lead to a sturdier device—the junction transistor. The first prototype of this kind was made in 1951.

Because the transistor is an amplifying device, it has a very wide range of applications in the electronics field. It is extremely small and requires very little power to operate it; for these reasons it is destined to have a profound influence on the design, for example, of computers, of Post Office equipment such as repeaters and exchanges, and of Service equipments of every kind for use on land, sea and in the air. For the reasons already mentioned, the transistor will also greatly modify the design of components.

One of the main lines of transistor development, both here and elsewhere, is towards types which can operate at the higher frequencies. In America types operating up to 10 Mc/s and over are already in production; the theoretical limit, speaking from our present knowledge, seems to be in the region of 1 000 Mc/s or at the most a few thousand megacycles per second.

Another semi-conductor device with an important future is

based on the fact that, when charge carriers are injected into a junction, multiplication occurs, rather like electron multiplication in an ionized gas. This effect can be used to produce very-high-frequency oscillations, and from the theoretical point of view perhaps eventually even in the region of centimetric waves.

The change between two possible energy states in molecules can be used for microwave oscillation or amplification, the interaction between a microwave system and a substance falling from a higher to a lower energy state enabling power to be extracted. One class of amplifier of this kind uses semi-conductors and provides *m*icrowave *a*mplification by *s*timulated *e*lectromagnetic *r*adiation, from which is derived its abbreviated name of Maser. This device can operate only at low power levels, and theoretically its efficiency and bandwidth are not great. However, useful gain can be obtained, and at the extremely low temperature at which it must be operated its signal/noise ratio is extremely high.

The ideas using solid materials for electronic devices, which I have outlined, are still so new that their importance and the extent to which they will be developed cannot be foreseen at present. It is possible, however, that they may provide the key to the whole field of millimetric waves.

Not the least important aspect of the great developments in this field is the enormous stimulus that has been given to research into the physics of solids. This field is growing in both volume and importance, and because of this we can undoubtedly expect this new science and technology to produce many novel and probably revolutionary devices and applications within the next few years.

Automation

Automation is no new thing and has been introduced in varying degrees into many industries ever since the industrial revolution. The reason, I believe, why so much attention has been focused on it in recent years is that, whereas formerly we made machines which could assist our physical efforts, we are now, largely through the application of electronics, able to make machines which can augment our mental efforts. We can give machines 'electronic eyes and ears', to use the Duke of Edinburgh's expressive phrase, and these sensing elements can feed back the information they receive so that any departure from the required result can be corrected. In addition, it is now possible to give a machine a programme which instructs it to perform certain operations or to react in certain ways. In complicated systems these relatively new elements—feedback and programming—lead to the use of computers and electronic memories.

It is, in my view, the social rather than the technical implications of automation which have attracted most attention. The two are, of course, interlinked, for if social conditions hinder the adoption of automation, then its technical progress and application are bound to be retarded. This aspect is a very broad and interesting subject which I will not refer to any further here, since I shall be opening an Informal Discussion on it before The Institution later this month.

Probably no other recent advance has had so many words poured out on it and has been so misunderstood. From what one reads and hears one could well imagine that it is only a matter of time before all our thinking and manual work will be carried out by machines. This is very far from the truth, and I feel it would be appropriate for me to attempt to put this new development into some perspective.

Within a volume the size of our heads we each have a brain weighing some 3 lb and consisting, I am told, of some 10 000 million individual cells,* which is about thirteen times the world production of valves in 1956. Among its countless other functions, our brain includes the equivalent of a compatible black-and-white and colour television system, a sound recording and reproducing system, and an ability to recognize complex patterns which outstrips any practical mechanical or electronic equipment. If it were possible to construct a machine able to perform the same functions as the human brain, it would inevitably have to be largely electronic; if we brought together all the necessary component parts and could then in some miraculous way solve the vast problem of connecting them together, we should still be faced with the fact that, even with the most reliable modern components, several hundred would be faulty at any given instant. On whether a machine is capable of having original ideas, I would comment that, without vision there can be no progress, and however far I look into the future I cannot conceive that any machine man may create will ever be able to replace the relatively few geniuses, such as Leonardo da Vinci, Shakespeare, Beethoven, Wren, Kelvin and Faraday, on whose vision and creative ability the evolution of our civilization depends. On the day man is content to leave all his imaginative thinking to machines he will be destined to a future without beauty, without hope, and finally without love.

* Bowden, B. V.: 'Faster than Thought.'

Entertainment: Radio and Television

In general, entertainment radio comes in for a great deal of criticism, and we should remember that it is on the enterprise and success of this section of the radio industry that the valve industry was founded. But for the existence of a large entertainment radio industry, with its know-how and manufacturing capacity, radar sets and other Service equipment could not have been produced in the necessary quantities at the start of the last war, and who can say what might then have been the outcome? Without a large entertainment radio industry at home we could not to-day market competitively oversea.

Turning now to television, if we consider either black-and-white or colour, we find in both cases that the major development efforts centre on the viewing tube. For black-and-white we now have the introduction of tubes with electrostatic instead of electromagnetic focusing, with the consequent advantages of reduction in weight, easier setting-up and little or no variation in focus with changes in mains voltage. The other principal alteration is the increase in cone angle, which in turn requires wider-angle deflection. Just after the war this was 55°, subsequently it was 70° and production is now in transition from 70° to 90°. A further increase from 90° to 110° is the next logical step, and can be achieved with little increase in scanning power by bringing the deflection coils nearer the electron beam through a reduction in neck diameter; this modification will necessitate a complete redesign of the electron gun. On a 21 in tube, increasing the angle from 70° to 90° shortens the tube by 3 in, and a further increase to 110° reduces the length by another 3 in. This permits the use of a smaller cabinet, which is more acceptable in most living rooms and is also cheaper. Because of these advantages there is no doubt that the trend to wider angles will continue.

While there have been a few non-entertainment applications of colour television, notably in the field of medicine, for general entertainment the main problem remains that of finding a means of viewing far cheaper than anything which has yet been put forward. Cheaper tubes have been suggested, but they invariably require more complicated and thus more expensive circuit design. The development of a suitable tube is proving a remarkably intractable problem which is all the more conspicuous because in these times we have become accustomed to the rapid solution of nearly every technical difficulty. Some solution will, of course, be found, since it is not in our nature to relinquish such problems unresolved, but it may well take a few years yet.

Possibly the final solution will differ greatly from what we might expect with our present knowledge, for I have often felt that the cathode-ray picture tube, not only for colour but also for black-and-white, is a rather cumbersome and inelegant device, and in 10 or 20 years from now we may well look back on it as we now look back on the spark transmitter and coherer.

Low-Temperature Devices

In its onward advance, electronics is constantly establishing links with fields which only a few years ago seemed quite remote. In recent years it has reaped much by its association with ferrites and semi-conductors, and now it is once again crossing the boundaries of new territory—this time into the low-temperature field. There are three main reasons why this advance is taking place; firstly, recent progress in low-temperature techniques has made the creation of temperature near absolute zero a matter of no very great difficulty; secondly, more complicated and therefore larger equipments costing, say, £100 000 or more, in which low-temperature facilities can economically be provided, are nowadays more frequently considered; thirdly, because of the extremely low noise level at temperatures near absolute zero, devices which operate in this region hold great attractions for the electronic engineer.

There are two main developments in low temperatures—I have already mentioned the first, the Maser, in dealing with semi-conductors. The second, the Cryotron, is a switching device which consists of a straight wire with a second wire coiled round it, both immersed in liquid helium and therefore having effectively zero electrical resistance. However, the resistance of the straight wire is restored when a sufficiently strong magnetic field is produced by a current in the coiled wire. The current required is only a fraction of that in the straight wire, and the effect can be produced within microseconds; the device thus acts as a very-high-speed relay. It has the advantage of simplicity and small size, and although it is too early yet to judge its value fully, it may well have wide applications in large computers.

Frequency Allocation

Frequency allocation is a problem somewhat different from those to which I have so far referred. I mention it here because of the supreme importance I attach to the use of what is an irreplaceable raw material, the ether, which in the fundamental nature of things is a strictly 'one-off' item. The growth of radio-communication, broadcasting and navigational aids has made the problems of frequency allocation more and more acute, especially during the last decade. International agreement has on the whole been good considering the complexity of the subject; and this is as well since the problem of interference has recently acquired a new facet with the advent of scatter transmissions, because these can cause interference here even though neither terminal is situated in this country. Somewhat in contrast to the international scene, some of us have doubted whether allocation at national level has taken the needs of all users sufficiently into account. Allocation to suit everyone is, of course, an extremely difficult task, requiring as it does the co-ordination and reconciliation of the needs of many diverse users and often involving security considerations. For all these reasons we should welcome the Postmaster General's statement in the House on the 3rd July, 1957, that he intends to set up a Frequency Advisory Committee to guide him on the broad aspects of frequency planning. I do not think I am revealing any secrets if I say that these proposals are very much in line with ideas which the Radio Industry Council discussed on a number of occasions with the previous Postmaster General.

EDUCATION AND TRAINING

This is the age of unprecedented advance on all fronts of applied science, when so much depends upon the skill and ability of the individual and when the nations of the world, almost without exception, are acutely conscious of the need to harness their man-power and material resources effectively in the struggle to maintain and improve their standards of living, to say nothing of their desire for international prestige and national security.

It is not surprising, therefore, that a good deal has been written in the past few years on education and training, pointing out the urgent need for a great increase in the number of adequately trained scientists and engineers. Some progress has been made, but the problem is being continuously reviewed from many aspects, for it is realized that our future progress industrially and therefore nationally depends upon the work of individuals of ability possessing the requisite learning and skills to enable them to sustain the immense activity necessary for the creation of new knowledge and the development of new technologies.

The importance of the individual in this respect needs emphasis, particularly in these days of increased mechanization, such as the development of automatic control techniques, data processing and many other labour-saving devices, for there is a danger of giving too much prominence to these things in the mistaken belief that man-power in consequence becomes less important. The contrary is the true position, however, for history shows that, in the long term, increased mechanization has not by any means led to increased unemployment. I do not intend to pursue this subject further, but I want to use this opportunity to suggest some lines of action which I believe to be necessary if we are to be successful in training a much greater number of suitably qualified technical personnel in a reasonable time and to the standard demanded by present-day conditions.

These conditions demand that the training of the potential scientist should include sufficient liberal studies to make him aware of and appreciate the social and economic problems of the modern world. At the same time, the potential classics man must acquire more scientific knowledge of a general character and so be able to appreciate the effects of scientific advances on modern conditions and to know something about the elements of science.

The question naturally arises: In what way can this be achieved? One suggestion is to raise the level of science teaching for all those in secondary schools, which, as I think is generally conceded at the present time, is on too low a level. Further, this teaching should commence at an earlier age than is the case at the moment, so enabling students to proceed to more advanced work at an earlier stage in their school life, at the same time assisting them to reveal and develop natural talents and preferences. However, we must not forget that in secondary schools the success of science teaching, even at the present level, is entirely dependent on the provision of properly trained teachers. The inadequate supply of suitable candidates for the teaching profession is a fundamental problem, and unless we can solve it the penalty will be severe and enduring.

Inevitably these suggestions raise the question of the amount of time available, and a solution of this problem may mean an extension of the period spent at school. The achievement of this objective may also require that more attention be given to 'non-faculty' subjects in assessing university entrance standards, which in turn would involve changes in the present accepted G.C.E. subjects at the advanced level. Some practical support to this line of thought would be given by the suggested Cambridge Honours Course combining science and the arts, which would also give encouragement to the sixth-form boy on the arts side to study science.

Referring to teachers for technical colleges, the report, 'The

'Supply and Training of Teachers for Technical Colleges', of a special committee under the chairmanship of Dr. Willis Jackson appointed by the Minister of Education in September, 1956, and published a few months ago, sets out very completely the nature and extent of the problem. Of special significance to this Institution and to the whole electrical industry is the statement of future needs, showing that a full-time teaching staff of 11 500 in 1955–56 should be increased to 18 600 in 1960–61, and part-time staff from 39 000 to 47 000 in the same period. Equally significant is the opinion expressed by the committee that educational institutions and industry tend 'to regard themselves as separate and distinct rather than as intimately associated partners in a joint enterprise'.

In spite of the many difficulties in its application, industry should most carefully consider how to implement the following statement appearing in this report: 'Industry . . . must be willing to accept and indeed to encourage and assist the transfer to full-time teaching work of experienced staff it can ill afford to lose as the only means of ensuring a much augmented supply of suitable recruits of high quality'.

Before leaving this topic, I would suggest to the electrical industry the need for a careful assessment and understanding of the implications of industrial training as part of the sandwich courses now being approved by the National Council for Technological Awards. These courses will be run by approved technical colleges and will lead to the Diploma in Technology (Engineering). The student gaining this award is assumed to be knowledgeable in both the fundamentals of science and technology and also in the practical application of this knowledge. It follows, therefore, that the purely academic training, and the technological training carried out in industry, must be treated as of equal importance in order that the award may denote an adequate standard of academic achievement and of competence in technological application. The danger is that the periods of industrial training may tend to be regarded as periods of normal employment unrelated to the academic part of the sandwich course. Should this become the general pattern, then the objective of producing technologists, that is to say engineers with experience of the practical application of fundamentals, will not be achieved. It is my considered view that industry must take an active part in determining the standards and requirements of the technological training and must insist on these standards being maintained.

The new course for the Diploma in Technology is only one of many factors which are increasing the demands for practical training, the burden of which is carried almost exclusively by the larger industrial concerns. There is a limit to what these organizations can do, however, and even though this limit has perhaps not yet been reached, it is clearly right and necessary that smaller firms should contribute their share to the pool of practical training facilities. A very few such firms are already contributing through co-operative training schemes, and they have shown that, given the right conditions, such schemes can be successful. Because extra men will be available owing to the bulge going through the secondary schools, and because of the tail-off in call-up, there is an urgent short-term need to provide additional practical training facilities, quite apart from the long-term implications of the position. It would be a disastrous paradox if, at the time when schools, colleges and universities are increasing their outputs in an attempt to provide the additional men which industry has called for over such a long period, industry itself should fail to have available the practical facilities without which training cannot be properly completed.

We must all welcome the Government decision for a progressive decrease in the numbers called up for National Service, which is thus likely to end in 1960; in addition, it is probable that in 1958 and 1959 not all those liable for Service will actually be called up. However, in these two years all trained men who have been deferred will continue to be called up even if more are available than the Forces require to meet their needs for skilled manpower. Obviously, industry could well do with this surplus. This waste of our most valuable commodity—trained personnel—is very disturbing, and one must hope that the policy behind it will be further considered.

Among the many aspects of education industry has to deal with is that of keeping its own technical personnel of all grades up to date with the many new ideas which are constantly coming forward. Usually this can be done by reading and by outside lectures, but occasionally, when quite a new concept is introduced, something more than this is needed. Transistors, for instance, require the engineer, who is accustomed to working with valves, to think in quite a different way. Instead of thinking in terms of voltage he must think in terms of current, and practically all his accustomed habits of design thought must be discarded. In such instances industry has the task of re-educating its own engineers, and some special effort is required. In the case of transistors the need has been met, in one instance, by the production of a film which explains the theory of transistor operation and then proceeds to the derivation of the equivalent circuit; such an approach enables the engineer to base his new ideas on the solid foundation of basic fundamentals. As electronics expands ever more rapidly into new fields, the valve industry will have to give increasing thought to this problem of re-education.

Recently the recruitment of larger numbers of women to the ranks of technicians and professional engineers has been increasingly advocated. In a country such as ours, which still holds rather definite views on the scope of women's activities, such a course presents its own peculiar difficulties and requires a change in outlook among parents and teachers and in industry. It is time we ceased to fear the shadow which the wedding ring casts behind and before it. Already this fear is less than it used to be; for instance, marriage is no longer a bar to some posts, in teaching and in the Civil Service for example. But we in industry are changing our ideas far too slowly. In the long run, I believe, prejudices will be overcome; let us hope the process does not take too long, because we urgently need at this moment the skilled contribution which, I am sure, suitably trained women have it in their power to give. The reason we turn to them is quite simple; they are the most significant source from which we can meet our persistent and dangerous shortages of trained personnel.

THE PRESS

I am very pleased to include in this Address some mention of the Press, because The Institution and the electronics industry owe so much to the support they receive from both technical and lay papers.

It is my view that the public require to be still better informed on scientific achievements and that there is a great deal more to be done in educating them to a deeper appreciation of the significance of our work as engineers. The chief means of closing this gap between science and those who work in other fields is through the lay Press, and we are grateful to them for what they have already done in this direction and for bringing our achievements to public notice. I am convinced that the role they are playing in this way will be of ever-growing importance.

One of the difficulties with which engineers are faced to-day is that the rate of advance is so rapid that many of us tend more and more to become specialists in our own particular subjects, and develop an increasing ignorance of other work which has no

immediate bearing on what we are doing. It is the technical Press which plays a major role in bridging this gap; it is also to the technical Press that we look for the broad and intelligent exchange of ideas and information, and for the publication of the results of our individual work. I like to think of the technical Press as complementary to the journals of the learned and professional institutions, the whole constituting a shop front in which we can display our scientific wares, not only amongst ourselves but also to other scientists all over the world.

It is appropriate to acknowledge the accurate and painstaking work of the editorial staff of our own Institution. When you consider the wealth of papers, articles and other publications produced by our members, and when you remember that all this, and a good deal more, has to be sifted, assessed, edited and presented accurately and intelligently in the various Institution publications, then I think you must all agree with me that our editorial staff does a really magnificent job.

BEYOND THE HORIZON

I conclude my Address by leaving with you a thought which I personally feel is of growing importance, not only for us as members of this great Institution, but for all scientists and engineers in all the countries of the world, and which may well become the most significant issue that members of professional bodies such as our own have so far had to face. I refer to our role as leaders, not in the sense of fitness for an executive position, but as leaders who accept the responsibility for guiding opinion on the significance and implications of scientific engineering advances, so that these advances assist the lot of mankind rather than the reverse.

We have invariably regarded it as right that we should be concerned only with establishing scientific truths, putting new knowledge to some practical use, producing some commodity at the right price, at the right time and in the right place, and showing how engineering science can be successfully harnessed to fulfil our many needs. With a few exceptions we have been little concerned with the social and political repercussions of our efforts; the use which others make of our work has far too seldom appeared to us to be of prime importance. I believe that the time will soon be here, if it has not already arrived, when more of us must be as much concerned with the results of our scientific and engineering achievements as we are with the work itself.

For instance, we have made automation possible—what is our responsibility for the social changes it will bring? Lately there has been considerable public discussion on the value of television; it is said that on these programmes some £18 million per year are spent by the B.B.C. and I.T.A. together. One cannot help reflecting whether the engineers who created this medium have not some special responsibility for the way in which it is used. They cannot stand aside and make no contribution whatsoever to current thought on these matters. The scientist must take part in government at the highest level, as exemplified by Sir Winston Churchill's appointment of the late Lord Cherwell as his scientific adviser during the last war.

However, it is in the military sphere that this question of our responsibility has appeared in its most acute form, and it is not a new problem by any means. H. D. Smyth of Princeton University, New Jersey, has admirably stated the situation in the first report ever published on the military use of atomic energy. Writing in 1945, he said, 'We find ourselves with an explosive which is far from completely perfected. Yet the future possibilities of such explosives are appalling and their effects . . . on international affairs are of fundamental importance. Here is a new tool for mankind. . . . Its development raises many questions that must be answered in the future. These questions are not technical questions—they are political and social questions and the answers given may affect all mankind for generations.' We are very little nearer finding an answer to these questions than we were twelve years ago when this was written.

In the meantime we now have a completely new situation, and must face the fact that the world has been brought to a crossroads; one road leads to the destruction of world civilization as it now exists, the other to a better life for everyone, not only in backward countries but in highly developed countries too. It is we, the engineers and scientists, who are largely responsible for this position, and surely we are morally responsible for the way in which our work is used. Can we, or dare we, stand aloof from the social and political implications of what we have achieved? I am convinced that this question must sooner or later be given an answer. I am equally convinced that this great Institution of ours has a vital part to play in framing that answer.

The Institution of Electrical Engineers
Abstract No. 2563
Feb. 1958
©

SUPPLY SECTION: CHAIRMAN'S ADDRESS

By Professor M. G. SAY, Ph.D., M.Sc., F.R.S.E., Member.

'TOO MUCH AND TOO LITTLE'

(ABSTRACT *of Address delivered* 23*rd October*, 1957.)

'Man never is, but always to be, blessed.' That perhaps epitomizes the theme of this Address: the persistent disparity between demand and supply, between what we need and what we have, between what we should do and what we can.

Mankind's Material Needs

In a broad sense, for his continued material existence man needs water, land and energy.

Life is biologically impossible without water. Ur of the Chaldees was abandoned when the Euphrates changed its course. The very existence of the oldest centres of culture and civilization was dependent on the skill of the irrigation engineer, who made possible the pyramids of Egypt and the hanging gardens of Babylon. Recent civilization, especially since the industrial revolution, has made heavy demands on water, which is often a valuable, saleable article.

Land means food. The longing of the land-hungry peasant for his own acre is the instinct of centuries of war against hunger. Again, modern living makes great demands on land, not only for its food-bearing potential, but also for its mineral store, its living and working space, and its yield of natural materials.

Energy

Even to-day you will find over the surface of the earth an almost complete gamut of stages of human development from the very primitive to the very civilized. An Asian coolie or a Latin-American peon, in sweat and toil, produces only one-hundredth of the energy that the average worker in the United States has at his command with no more effort than pressing a button or closing a switch. And muscle energy, human or animal, is twenty times as costly as nuclear energy from Calder Hall. The effort of three out of four Chinese workers is needed to feed the nation, compared with three in six for Japan and Russia, and three in twenty in the United States. Throughout the under-developed countries—three-quarters of the habitable world and two-thirds of its population—a demand is beginning for auxiliary energy, so that life may be raised to a standard less pitifully low.

Oil is mobile. Energy in electrical form has, till now, been substantially confined to the terrains of coal or water power. With the advent of nuclear energy it has become foot-loose and related but little to geography or geology: it can go anywhere, however primitive. But matters are not as easy as that. Peoples may remain poor and their land undeveloped because poverty puts out of reach the opportunity for the energy that would deliver them from that poverty. Poverty can breed poverty, and it may be very hard indeed to afford to take the first step.

China, until recently regarded as a vast, permanently-peasant country, shows signs of interest in the development of energy resources with their concomitants of industrialization and social engineering—health services, schools, communications. Yet she has postponed large-scale mechanization of farms for at least another decade. Production must be increased by better use of man-power and animal labour. Labour is cheaper than machines, and tractors are luxuries that cannot be afforded yet.

The picture is very different, of course, in North America, Western Europe and the Soviet Union, where the power available per head of the population is taken as a standard (possibly even *the* standard) of civilized life. All these regions are increasing energy resources as fast as they are able and in many different ways. France has launched the world's first enterprise for harnessing the ocean tides, with a plant at the estuary of the River Rance in Brittany using back-up pump-storage at high tide to give a greatly increased return when the impounded water is released. The six countries of 'Little Europe' are planning to link up in a European nuclear energy pool with a target of 15 000 MW in ten years' time, calling for immediate action and co-operation from Britain and North America. At home, it is now a year since the world's first public electricity supply was furnished by a nuclear station. No one else has as yet achieved generation on the same scale or at such a low cost.

The picture is changing in other continents, too. India is developing conventional hydro-electric energy resources: she also has a nuclear programme, and is actively stimulating village industry to employ the new magic in a way that does not disrupt the customs and conventions of rural life.

Energy demands are racing ahead. An industrial nation needs only two assets to ensure a spectacular improvement of its living standards: cheap abundant energy, and a virile, resourceful population. So thought the British Minister of Power, sponsoring the £5 000 million programme for the development of conventional and nuclear generating stations and for the modernization of the coal mines—and this to provide only for the next ten years. What of the next fifty?

World Population

The human race now numbers 3 000 millions. There are 600 millions in China, 400 in India, 200 in the Soviet Union and 180 millions in the United States. The death rate averages one-half of the birth-rate of 5 000 every hour, 40 millions every year. In Asia alone the annual increase is 24 millions. In 50 years' time, at present rates, the world population will be 6 000 millions, or double its present size.

Only a fraction of the earth's land area is fertile and in a climate suitable for the growth of vegetation, and it takes an acre to feed a man. In the United Kingdom, with only one half-acre to each member of our people, it is not surprising that we import 40% of our food.

The growing problem of feeding the multitudinous human mouths has for long engaged sociologists' thought. The future problem of food is one of the clearest examples of too much and too little, creeping up on us inexorably, and fast.

There is another aspect: that of energy needs. It would be difficult enough to cope with the accepted normal rate of rise of energy demand, but with a population doubled in 50 years, and vast countries becoming developed, the problem is greatly intensified.

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World Energy

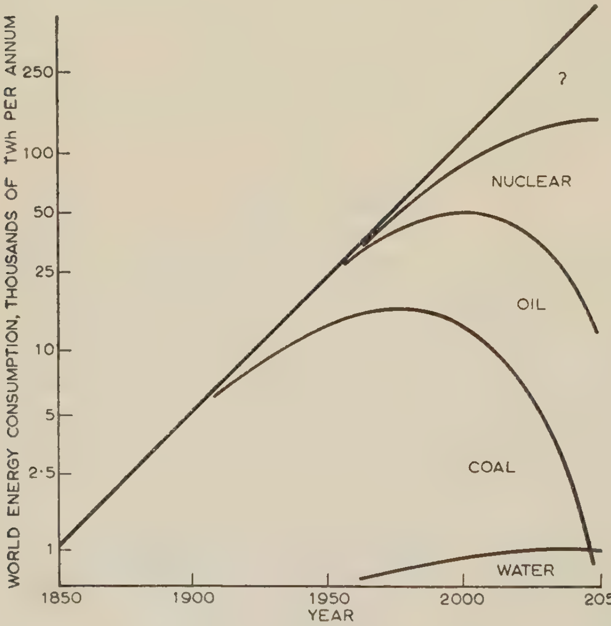
U.N.O. estimates that the yearly increase in world energy demand averages 3¼% compound. In 1950 the global demand was of the order of 30 000 TWh.* In the 1920's the demand was met primarily from coal. Thereafter oil began to play an increasing part, and from 1940 natural gas has contributed largely; in fact, three-quarters of the increase since 1920 has been with oil and natural gas, and one-twentieth by hydro power.

In A.D. 2000, little more than forty years ahead, the world's energy demand will, at present rates, be well over 100 000 TWh per annum, three times the present figure. Some of this can be supplied by substantial development of oil and natural gas, but the reserves, as with coal, are limited. There is only so much, and no more. Estimates suggest that world resources of primary fossil fuel will be near the point of exhaustion within a century, in the lifetime of our grandsons. The development of alternative sources of energy is well recognized, even by the layman, as a matter of absolute necessity: a matter, literally, of life and death.

Oil is distributed in a manner fraught with dangerous possibilities. The United States possesses one-fifth of the world's known oil store, and is using it at an annual rate of 8%. The Middle East has two-thirds, and is extracting only 1% per year. The Middle East must remain the major source of oil for Western Europe, and soon will support the North American needs, for the United States is already, on balance, an importing country. The essential community of interest between these three regions is bedevilled by political unrest, as recent events have shown. The importance of Middle-East oil to Western economy can only be counterbalanced by very considerable alternative energy supplies. What will these new sources be?

Nuclear energy is, of course, the obvious answer, although we must not forget that (at any rate, at present) there may be no substitute for oil (as motor, aviation and agricultural fuels) or no easy substitute (as a lubricant).

Look at the diagram. It is a simplified statement of the past and a speculative forecast of the future. The straight diagonal



line represents total world energy demand on a base of time in years. Coal production is nearing its zenith, with mechanization keeping pace—but only just—with the increasingly difficult coal-winning conditions: it must soon start falling. Oil production is increasing fast, but again the stocks are not inexhaustible and scarcity in the future is bound to come. If the need is to be met, the difference must, at least initially, be made up by nuclear energy. At first sight the curve suggests that, with an effort, the deficiency might be met. But notice the ordinates: they are logarithmic. The further on in time, and the further up the energy scale, the larger becomes the gap to be filled.

A century hence even nuclear energy may be insufficient, or perhaps will not meet particular kinds of need, and we may have to direct the search to sources of an almost cosmic scale. The earth's annual heat loss of 200 000 TWh may be tapped. The tides might give us 30. The sun sends us every year an energy of 1 500 million TWh, but only one-sixth of it reaches the land surface, although some of the rest becomes the motive factor of water power and photo-synthesis.

What will it be like in two centuries from now?

An Age of Waste?

The mounting problem of food for the world's millions makes clear the urgent necessity for land conservation and the rescue of good farmland from industrial development. The engineer has the technical responsibility for devising soil protection, combating soil erosion and reclaiming land from the sea. Too often the vital asset is being lost. The North American dustbowl loses vital fertility every year. Even in East Anglia the soil has begun to blow—as yet in a cloud no bigger than a man's hand, and nothing that could not soon be put right. But it is not being put right. Farming as a science needs the engineer: farming as an art will not survive his heavy hand. Tractors and chemical fertilizers are not complete substitutes for livestock. There is, curiously, a comparable case at the other end of the scale. Indian engineers have devised a solar-energy stove which can cook a meal for a whole family; but it would cost the Indian peasant a two-months' wage, so he goes on burning as fuel the cow dung which should be feeding his manure-starved soil. He has too little; perhaps we have too much. The result seems, in some ways, to be the same. Dare we forget that, as we lived by the land before the industrial revolution, we might have to do so again?

To turn nearer home. Of the primary fuel we use for the generation of electrical energy, four-fifths is wasted. In A.D. 2000, if this continues, the annual rate of energy waste will be approaching 80 000 TWh, more than twice the total present world consumption. Unless this tremendous loss is somehow curbed, our times will come to be known to a starved and shivering posterity as the age of wanton waste. It has been said that the energy consumption in the United States since 1850 has equalled the complete global energy use from prehistory until then. And 80% of it has been thrown away in the sense of not having been used in a manner or for a purpose that could, by any standards, be described as useful. All civilized countries are squandering their natural resources, and only water power significantly uses revenue rather than capital.

Reduction of waste would itself go far to meet the rising tide of energy need. The most obvious urgency for higher thermal efficiency is certainly receiving intensive study. The difficulties are very great, especially in the metallurgy of high-temperature metals, and it must be admitted that the progress is slow. Every one-percent increase in thermal efficiency is arduously bought. The problem can, however, have another attack, and it seems inescapable that power-station heat—of which there is a great and growing quantity—must eventually be used more profitably. Should we not also press more insistently for heat-pump development to tap the vast natural supply of low-grade heat? It is

* In problems of this magnitude we need units on the grand scale: 1 terawatt-hour (TWh) = 10^3 gigawatt-hours (GWh) = 10^6 megawatt-hours (MWh).

true that a large proportion of the total energy demand is needed by man simply to keep himself warm. That necessity has been with man ever since he lost most of his body-hair: it seems racially suicidal to wait for mere financial economics before we try to engineer an established scientific method of great advantage.

Why should it not be Britain that makes a major contribution to the reduction of waste? It is of vital interest to us to do so, we have so much to gain. After all, phenomenal discoveries have been made before; epoch-making in the literal sense, like Faraday's.

Native Genius

Michael Faraday, says Sir Lawrence Bragg, may justly be acclaimed as our greatest scientist since Newton. Starting life as a bookseller's apprentice, his interest in science came to the notice of Sir Humphry Davy, who engaged him as laboratory assistant at the Royal Institution, where he later succeeded his patron. Faraday had no scientific training except what he picked up as Davy's assistant. He knew no mathematics, he used no formulae. Yet it fell to him to reveal more secrets of nature than any other man. By our standards the young Faraday had too little opportunity and was saved by a stroke of luck. But what a harvest!

The Supply Section could not have a more estimable patron saint than Faraday. He had a delightful personality—modest, spirited, courteous, considerate, and deeply religious. He could have made a fortune, but dismissed the chances because they interfered with his work, and died poor. Yet no one has enriched his country scientifically more than he. If we could breed no more than one or two of his like every generation, the material future would hold no doubts.

Achievements

Even without Faraday there has been, and is, high quality. British invention and discovery is not a book, closed and gathering dust, while enterprise goes on elsewhere. The gigantic developments in the United States, founded on natural resources and an unmatched human vigour, seem to obscure our own achievements. But Britain, too, has made an outstanding contribution: Swan's lamp, Fleming's valve, radar, the magnetron, the jet engine. The originality of our scientists in nuclear research is matched by our engineers' supreme contribution in breaking through the barrier of the unknown, untried technology and translating energy equations into working plant. It was an act of faith, with the risk of essential technical information being short at the time it was wanted. We are playing a part in research, philosophy and practical development. We are not a spent people, and there is still endless scope for ingenuity, contrivance, enterprise.

Survival

There is need. In a material sense Britain lives, and can continue to live, only by exports, to which engineering industry contributes a major part. Raw materials, even some coal, must be imported, and sent out again in manufactured form with enhanced intrinsic value. Increased industrialization elsewhere already threatens our export markets. We see Canada emerging impressively: Russia will be the next. Fifty years hence the industrial lead may have shifted to China. The effect on our own economy cannot be less than profound.

The ideal export is the ingenious idea, the well-based scientific plan, requiring a pennyworth of ink and paper but carrying a pound's worth of brains and experience. Ideas and knowledge will always command a price. Ingenuity, like idealism, is most commonly characteristic of the young, whose innate genius and skill awaits only the opportunity and the stimulus. How are we to educate them so as to foster those gifts?

The Engineering Career

We need the budding Michael Faradays. They must not slip through our fingers. But there are some antagonistic factors. Professional engineering is an activity demanding brains and character. It is not a career into which a dull-witted youth can be shunted *faute de mieux*. Learning to be an engineer is a five-year stretch of hard labour, in which social life (in Redbrick, at any rate) is restricted, clothing a necessity not a pleasure, saving impossible, holidays a time for extra work, independence far ahead. The boy who leaves school at fifteen, ten years ahead of the fledged engineer, can often earn a wage that gives holidays, clothes, savings, independence, and every evening free. The sweet grapes are tempting.

Again, a professional engineer on the way up will rarely work less than 60 hours a week, 40 on the job and 20 in the study clearing up one day and preparing for the next. Some will-power and a considerable sense of vocation are needed to resist the many distractions of modern civilized life.

So it is surprising, not that there are so few engineering undergraduates, but so many, when the counter-attractions appear so strong. With characteristic materialism the Russians, we are told, make their professional engineers the aristocrats of labour, rewarded with the highest salaries, the best cars, and the most sumptuous holidays on the shores of the Black Sea.

Engineering Education

Education for engineering has had so much recent publicity that to discuss it at any length would be tedious. It does, however, fall so obviously into the theme of this Address that something must be said.

British secondary education has often been accused of a classical bias, and the allegation has as often been denied. The fact remains that when we hear about the gigantic Russian output of trained engineers, we take fright and start planning an intensification of technical training. It is worth the observation that in Russian secondary schools the three final years to age 17 include the study of physics, chemistry and mathematics for 40% of the time. This is for all pupils, not just some: and they must pass in these subjects, as well as in the standard assortment included in the other 60%, in order to enter a university. So potential arts men answer up to science tests, and potential engineers to literary tests of a level quite beyond the average British technical student.

This is, perhaps, too harsh. Many excellent humans are completely mathematics-blind, and compulsory examination in that subject could cause them cruel and unnecessary suffering. But without going into details, it is at least arguable that all our youngsters should have the opportunity to get the *feel* of science. I believe that most (though not all) engineers are made, not born, and that a lad of parts could equally well become a good surgeon as a good engineer, according to the way in which his interests were first aroused.

It must be admitted that unmitigated science has some educational disadvantages. It is about things, not about people. Scientific thinking means deep and constant thinking about a narrow field among inanimate things. This is an excellent discipline in its way, but (as C. P. Snow has pointed out) there is another discipline which depends on thinking in breadth about a lot of things at once. In almost all activities except the purely scientific the second is the more important to a proper conduct of life and its complicated problems.

There is, of course, the other half of the school curriculum able to redress the balance. It *can* be about people. Social

history could include the history of science, to show what it has done to our society, and what it may do—even the damage it may do—to our society in the future.

Were school courses less specialized, more broad and humane, then first-year science and engineering undergraduates would not start at the same level of professional knowledge as they do now. Inevitably this means either more university time, or curricula of lower factual content. The latter, in my view, is the more rational. The English universities rely on Intermediate Science level at entry, obtained through the G.C.E., and start their undergraduates in what is roughly equivalent to the second year at a Scottish university. It is, I think, a fact that Scottish schooling is broader and less specialized than English, and the Scottish universities are adamant in keeping their first year general science and mathematics. I am not going to say which is right, though my personal feeling is that there may be less wrong north than south of the Border.

There is an interesting too-much-too-little backwash of this state of affairs. Engineering places appear to be generally at a premium in most English universities; in contrast there is rather more room in Scotland. Why this should be I do not know, but the potential of the Scottish universities for absorbing the English overflow is made almost valueless by the difference in the two systems of secondary education.

Learning to be an engineer is a specialized discipline. Specialization is not necessarily bad; it is certainly unavoidable, and it has a very long history, as some of our common surnames will show. And who, anyway, would have a major surgical operation performed by a medico with a good, broad, general education rather than by a specialist, however uncouth? The dexterous knife is more important then than the subtle literary allusion or the Latin tag. But humanly speaking, specialization is tolerable only if the more rarified peaks are set in a fertile landscape of culture and appreciation. The necessary specialization must, quite simply, not be too early.

Academic Change

For many centuries the universities were almost the sole guardians of learning, the study of the lore of the ancient Greeks. Latin was the *lingua franca.* The academic mind was conditioned by contemplation and conservatism. With the ancient arts the upstarts, science and engineering, make strange bedfellows. The swift growth of scientific knowledge, much of which is being applied as fast as it can be engineered, means rapid and continuous change in outlook and emphasis. Every opportunity must be taken to co-ordinate and concentrate fundamental ideas. At this level we need more bedrock and less technology.

I am not myself called upon to design 250 MW generators, but I am sure that the approach is very different from the humdrum empiricism typical of design courses in my student days. Modern design is design to the limit, and the limit must be thoroughly understood through fundamental mechanics, thermodynamics and knowledge of material behaviour, and be aided by all possible computational assistance to engineering inspiration.

Technology can take too great a place in the university curriculum, although it is only fair to say that many are aware of that. Technology is best acquired in the works. Again I would like to take an example from the electrical machine. Great strides in co-ordination and clarity, emphasizing the oneness of electromagnetic machines, have already been made at a high level by Gabriel Kron, and at a less advanced (but more practical) level by such writers as Gibbs and Adkins. In these studies, all machines are included, as they should be, in a single comprehensive conspectus, ideal for treatment at university level. For some years I have been trying to develop a co-ordinated treatment suitable for primary electrical-engineering education which fines down the subject and shears off much particularized technological excrescence. I can only report that the academic reaction has, so far, been strongly—even abusively—against me. I go on undismayed in the belief that a small contribution can so be made to solving the persistent problem of containing too much material in too little time.

What is it all for?

Electrical engineering education, like much other education, is inevitably vocational. But a way of livelihood is not a way of life. There is a growing feeling, expressed most cogently by those young men who look back in anger, that there is something lacking in the way of life engendered by a deadly feature of the way of livelihood.

Lewis Mumford, in 'The Transformation of Man', thinks that we have arrived at a point where man will either relapse into an elemental barbarism or, to avoid it, take the step out of his mechanical frustration into a higher form of life altogether. Man's development has been powered, not solely by intelligence, but also by instinct and by the awareness of himself as an individual possessed of imagination and creation, a key element in his make-up. That key element is being exterminated under the pressure and strain of a mechanistic age; man is losing the secret of how to make and keep himself human. The present stage cannot last, for it lacks the necessary humanist validity for permanence, even if it were worth having in itself. For industrialization is not an end in itself: it is not good or bad intrinsically. It is either a good or a bad servant.

It is very difficult to put these ideas into words. Sir John Maud uses the word 'cogmanship' to describe the real, to some a terrifying, danger. He defines it as that impersonal relationship of cogs-in-the-machine which always threatens industrial society. We cannot deny that the threat exists, nor on the other hand that industrialization has brought great benefits to mankind. It will bring more, but only if the mastery remains where it belongs —in the care of the human spirit.

What makes a man work happily, willingly, satisfyingly and well? We may regard work as a vocation, or a slavery, or a necessary evil to be borne, or a self-expression. It ought to be a self-fulfilment. J. B. Priestley, in a play called 'Summer Day's Dream', pictures Britain in 1975, down and out as an industrial nation, living barely but satisfyingly on the land, but with its people rewarded by something scarcely definable except by a cliché: they had 'found themselves'. Many writers, particularly poets, hammer again and again at this problem: *what is it all for?* The problem is not a new one, but it is intensified by the increasing yoke of industrialization. No wonder there are angry young men.

We make intense efforts to keep going so that we shall, in the future, be able to keep going. No doubt we do so because we must, but it would mean so much more if we understood, not only the economic, but also the spiritual necessity. When I started this Address I referred to three needs. I was careful to call them 'material'. Modern man's fourth need is the answer to the question: What is the aim of human life?

What will it be like in a century from now? The engineer, conditioned as he is by his own limitations and by the technological lore of the times, cannot but boggle at the thought, and cannot give an answer even in material terms. That would need a Verne or a Wells, with free and untrammelled mind, to speculate upon. It is worth the remembering that not a little of their fiction has become fact, that logical science can, in a sense, be outrun by the imaginative mind. We should also encourage and listen to philosophers, and poets too, for guidance. What we predict on quite logical, material grounds may never happen: it may be utterly changed by an idea. Remember how, in 1940,

a nation defeated and without resources was roused to resolution and defiance by the words of a man of faith?

I expect that some may accuse me of a dewy-eyed idealism. If so, I take it as a compliment. My own belief is stated far better than I could ever do by some lines by W. E. O'Shaughnessy:

> We are the music-makers,
> And we are the dreamers of dreams;
> Yet we are the movers and shakers
> Of the world for ever, it seems.
>
> One man with a dream, at pleasure
> Shall go forth and conquer a crown;
> And three with a new song's measure
> Can trample an empire down.
>
> We . . . Built Nineveh with our sighing,
> And Babel itself with our mirth,
> And o'erthrew them with prophesying
> To the old of the new world's worth.
> For each age is a dream that is dying,
> Or one that is coming to birth.

The Institution of Electrical Engineers
Abstract No. 2564
Feb. 1958

MEASUREMENT AND CONTROL SECTION: CHAIRMAN'S ADDRESS

By H. S. PETCH, B.Sc.(Eng.), Member.

'METERS AND METER ENGINEERS'

(ABSTRACT *of Address delivered 8th October*, 1957.)

I am deeply conscious both of the honour and the responsibility of becoming your Chairman for this new session. I regard my occupation of your Chair as a compliment to a diminishing group of meter engineers out of whose association this Section was formed nearly thirty years ago.

It is customary for a Chairman to address you on a subject about which he is reputedly knowledgeable. Accordingly, I propose to say something about meters and meter engineers, and I shall naturally approach the subject from the standpoint of an Electricity Board meter engineer. Much of what I shall say will be well known to those familiar with meter engineering, but I hope that it will be of interest to the preponderance of the Section's membership.

Meter engineering is the oldest part of this Section's scope. Time has inevitably resulted in many of the subjects of our earlier discussions becoming established principles and practices. Nevertheless, meter engineering is still far from static. There are plenty of technical and economic problems awaiting solution, and it is regrettable that for various reasons so few young minds are to-day attracted to the subject. The youngest meter engineer on my own staff is 42! My primary aim in this Address is to endeavour to improve this situation.

A meter is the focus of quite a number of powerful interests. Electricity consumers and Electricity Board accountants are equally concerned, though in opposite senses, that meters shall register correctly. The State brackets meters with other weights and measures and has produced an array of legislation dealing with them. Electricity Board commercial departments press for the addition of special features to meters in order to increase electricity sales. Electricity Board chief engineers, usually under financial stress, are inclined to regard anything to do with meters as utterly unproductive expenditure, but nevertheless welcome the economic pressure which meters engender to provide the diversity essential to electricity distribution at reasonable cost.

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When trying to find a way of living with all these interests, which so often conflict, the meter engineer is usually most successful if he falls back on the basis of all engineering, and satisfies himself that he is ensuring an adequate technical job at a minimum cost.

I should like to state my views on what constitutes an adequate job in this case, and to mention some methods of minimizing costs. I shall deal mainly with meters for domestic consumers, as the cost aspect is obviously most relevant to them. The problems associated with more complex metering equipments for large supplies are more exciting and offer much scope to the technically minded, but the Electricity Board meter engineer must regard these as 'plum cake', to be enjoyed after the 'bread and butter' of large quantities of simple meters.

Put briefly, a meter engineer's duties include the obtaining of adequate meters, conforming to the State's requirements and obtaining certificates for them, ensuring that adequacy persists when the meters are installed, deciding when ultimate loss of adequacy in service makes changing necessary, and, finally, reconditioning the meters to their original adequacy. I shall deal with these points in turn.

I think a meter may be said to be adequate for presently foreseeable British domestic conditions if it will meet the following requirements:

(*a*) Integrate the energy passing through it to an acceptable degree of accuracy when the load lies between 20 watts and 15 kW, when the voltage, ambient temperature and load power factor may be varying over appreciable ranges.

(*b*) Withstand being carried over considerable distances by normal transport, and being installed by average labour, and then continue to work in hot, damp and dirty surroundings.

(*c*) Be capable of being read in poor light, and be relatively noiseless.

(*d*) Continue this standard of performance for twenty years without attention.

(*e*) Finally, be capable of being restored easily to its pristine condition after that time.

I have used the words 'acceptable degree of accuracy', and these require further consideration. Three factors control such acceptability:

(i) The State imposes limits of initial accuracy for certification and slightly wider limits in service.
(ii) All meters, because of inevitable wear, show some falling off in accuracy with time.
(iii) The relation between meter production costs and accuracy as delivered by makers is a hyperboloid curve.

Expanding these a little, experience shows that, at the present price, meters are available having satisfactory performance with accuracy consistently within a band of $\pm 1 \cdot 5\%$, which is reasonably within the State's initial requirements (Fig. 1). Experience

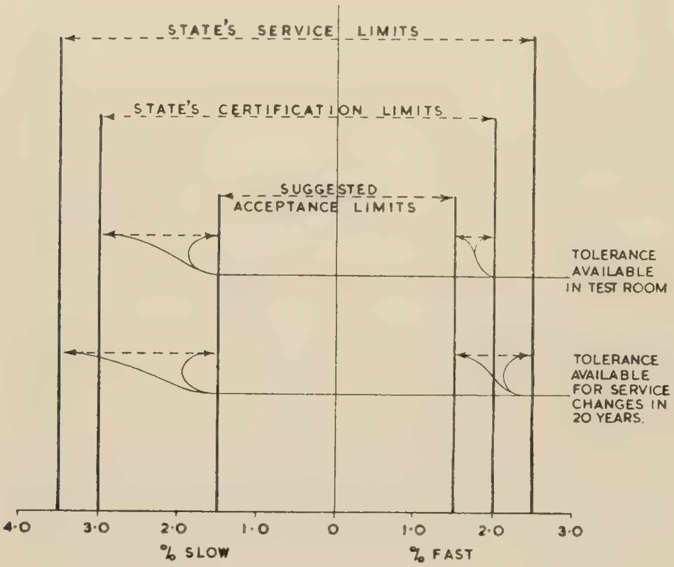

Fig. 1.—Meter limits of error.

also shows that some meters of similar design, when tested after 15 to 20 years' service, are in the main still within the State's service limits.

Mr. Whitehead, in his Chairman's Address in 1954, gave some figures which suggest that the specification of an as-delivered accuracy band of $\pm 0 \cdot 5\%$ would increase production costs by 77%, and that a widening of the band to $\pm 2 \cdot 5\%$, which is right on the State's initial limit, would only reduce production costs by 27%.

It therefore seems that adequate meters should be delivered with their accuracies consistently within $\pm 1 \cdot 5\%$, and they should then need no adjustment by the Electricity Board upon receipt. The specifying of a closer band of accuracy merely gives rise to unnecessary expense.

The acceptance of a wider band of accuracy will only shorten the period before wear makes changing of the meters necessary, and this can be shown to be uneconomic in the long run.

The most vital determinant of adequacy is the expected accurate life in service, and the meter engineer can only be guided here by his experience and judgment. Obviously the braking magnet must be truly permanent, and the magnet structure completely rigid. Similarly, the main framework of the meter and the electromagnetic driving system must be dimensionally stable, and the adjusting devices provided must be securely locked. Generally speaking, simplicity in these matters tends to stability. The gasketing of the cover must be good and permanently effective. The register must be designed to have the lowest possible initial friction, and, equally important, the design must be such that this friction remains as constant as possible. Finally, the rotor-bearing system must be superlative, and this requires special mention.

Much research extending over many years has been directed towards the design of meter bearings. Members of this Section, and in particular Mr. G. F. Shotter, have received the acknowledgments of the world for their work in this field. I can only touch on the fringe of it here, and do so mainly in the hope of stimulating younger men to take interest. A series of E.R.A. reports is available for closer study.

The problem, expressed simply, is as follows

(*a*) To provide substantially frictionless lower and upper bearings which will properly constrain the meter rotor against the very complex system of forces acting upon it, both when it is rotating and when it is at nominal rest under the influence of voltage alone.
(*b*) To reduce the effects of wear arising from these complex forces to a negligible amount over a 20-year period.
(*c*) To prevent damage to the bearing surfaces by mutual impact arising from normal handling.

It should be noted that the area over which there is actual contact between surfaces in meter lower bearings has to be so small, in order to keep down frictional retardation, that although the rotating part weighs less than 20 grammes the initial working bearing pressure approaches the crushing strength of the materials.

The five currently available constructions are shown diagrammatically in Fig. 2. A, B and C are in common use in British meters. D and E are predominantly American, although D is in use in Great Britain. Constructions A, B and C use carbon-steel pivots running in synthetic-sapphire cups. A and B are

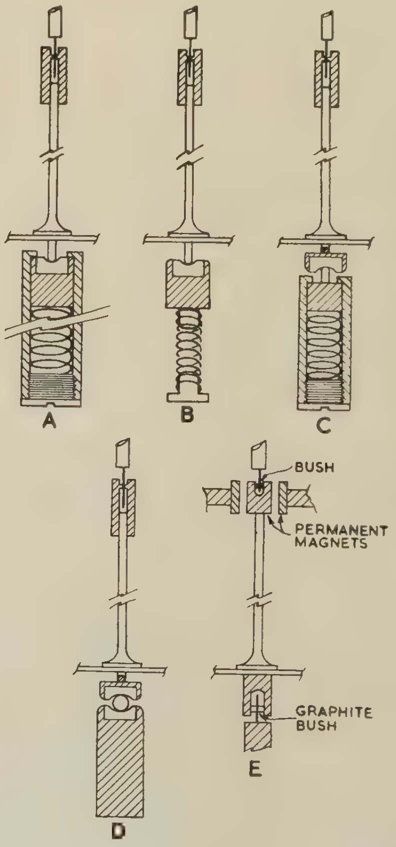

Fig. 2.—Meter-bearing constructions.

oiled, which appears to float the abrasive products of wear away from the working surfaces. Wear products are claimed to drop away in construction C. Construction D is interesting in that the ball is made of non-oxidizing material, and although often run without oil, such wear products as form are thereby claimed to be relatively innocuous.

Wear, which controls life, is of great concern to the supply meter engineer, and as Mr. Shotter has demonstrated, the tracking wear which takes place when the rotor is not revolving appears predominant in life determination. Mr. Shotter's paper on the subject* includes diagrams of the tracking movement and the remarkable distances traversed by the point of contact between bearing surfaces in a year. These sometimes exceed one hundred miles. It should be noted that in construction D the free ball should follow the tracking movement by rolling, so that wear should be much reduced.

The record of jewel examinations after prolonged service indicates that constructions A and B show a failure rate varying from 15 to 50% according to the make of meter, whereas constructions C and D show a failure rate of less than 5%. The good performance of construction C may be due to the fact that the only meter design which uses it has rather lower than average working forces, but may justify the claim that wear products fall away. The good performance of construction D makes it attractive to the supply meter engineer. The avoidance of oil is a practical advantage since oiling is an operation requiring skill, and skilled work in the simple job of servicing single-phase credit meters should be avoided on the score of cost. It is not without significance that three of the four American meter makers use construction D.

I have no comment on the magnetic suspension construction E, as I have no available information of after-service examinations.

There is still much scope for work on meter bearings. To my knowledge no exhaustive study of possible materials has been made. The exact physical nature of the present bearing surfaces is not known. The possibilities of irradiation or exposure to neutron flux as a means of producing a thin hard bearing surface on a more ductile base material could be explored. The exploitation of the very low friction of polytetrafluorethylene for top bearings could be studied. Solid laminar lubricants may well offer advantages.

I hope that the foregoing somewhat lengthy attempt to define an adequate meter will have established that, in meters as in other things, the best is usually the cheapest, and that meter engineers' insistence on high quality is firmly based in economics.

We in London have found it well worth while to take a 1% sample from every delivery of meters and to test this sample a good deal more thoroughly than the normal testing-station procedure permits for the bulk of meters. This has the merits (*a*) of keeping manufacturers 'on their toes' by early detection of drifts away from their usual high standards, (*b*) of making it possible to tell the routine testing stations of the critical load points at which they should test, and (*c*), since the samples are ultimately installed, of making it possible, if desired, to recall them after various service periods to make fairly precise check tests for service life without waiting for ultimate failure.

Having obtained what he judges to be adequate meters, the meter engineer's job has only begun. He has first to meet the State's requirements, in order to secure certificates for the meters. It would take too long to go through all that this involves in detail, but, briefly, each meter must be tested in a prescribed manner, and the results recorded for subsequent scrutiny before the certificate is given. It would be unfair to the officials concerned for me to give any impression of applied unreasonableness, as over the years they have always shown sympathy to the desire to reduce the cost of this work, but I must record my opinion that, in the present certification procedure, the State is requiring a more than adequate job, at least so far as modern meters are concerned.

First, as regards paper work, the detailed recording of test results for every meter involves much clerical labour, and has already produced a great mass of paper (of the order of 200 000 sheets in London alone) which must be filed for many years, and which is very rarely referred to. The certificate of the head of a testing station that the errors of all of a batch of meters are within $\pm 1 \cdot 5\%$ (i.e. well within the State's limits) should suffice to enable the examining authority to issue its certificate, provided that the latter authority is able to make checks on, say, a 5% random picked sample from the batch. No record beyond a list of numbers would then be needed. Such sample testing is accepted in other countries. Secondly, the State should drop its requirement of an electrical dial test on modern meters.

There are two broad ways of determining the accuracy of meters. One can compare the speed of the meter rotor with that of a known substandard meter carrying the same power. This method is quick and convenient, as I hope shortly to demonstrate. Alternatively, one can pass a quantity of energy through the sample meter and a known substandard and compare the register advances of the two meters. This method is slow and requires extensive accommodation for simultaneous testing of large batches. It also complicates and so increases the cost of all meters, because testing dials must be specially provided in order to reduce the testing time to a reasonable amount. It is the necessity for these fast-moving testing dials which restricts the use of cyclometer registers, which may become essential in the future in view of the increasing necessity for relying on consumers reading their own meters. The slow electrical dial test method is now required by the State. All that can be said in its favour is that it may show up an error in the gearing or dial marking of a meter, but it is not certain to do so. The record, for modern meters, shows that in reputable factories 100% checking methods have eliminated gearing errors, and the risk of dial marking errors could be eliminated at no significant cost by a simple scheme of interference pins and holes to prevent interchange of dials and registers. Even with the slow electrical dial test the dial marking is checked by visual inspection.

I consider this proves the case against dial testing.

Doing an adequate job next involves the meter engineer in trying to ensure that his adequate and certified meter reaches the consumer's premises and is installed there in good condition.

This is also too involved a matter to discuss fully here, and I can only say that it offers scope for thinking, as no universal and completely satisfactory methods seem to be known. Some thought has been given to a universal carton, which, if available, would probably solve this delivery problem, but the range of meter dimensions makes difficult the design of such cartons at reasonable prices.

The next phase of the meter engineer's adequate job is to decide when it is economic to change meters because their errors have reached values where the loss of revenue justifies reconditioning. The procedure is straightforward, involving either regular testing of samples of meters which are removed for incidental reasons, or, alternatively, regular tests of meters on site. Fig. 3 shows the distribution between age groups of errors found in off-circuit tests of a number of older types of meters.

If one makes the reasonable assumption that the error of a meter at 25% of its full-load rating represents the loss of revenue arising from it, and applies this to the same groups of meters,

* SHOTTER, G. F.: 'Parasitic Forces existing in Induction Watt-hour Meters', *Proceedings I.E.E.*, Paper No. 832 M, March, 1949 (96, Part II, p. 729).

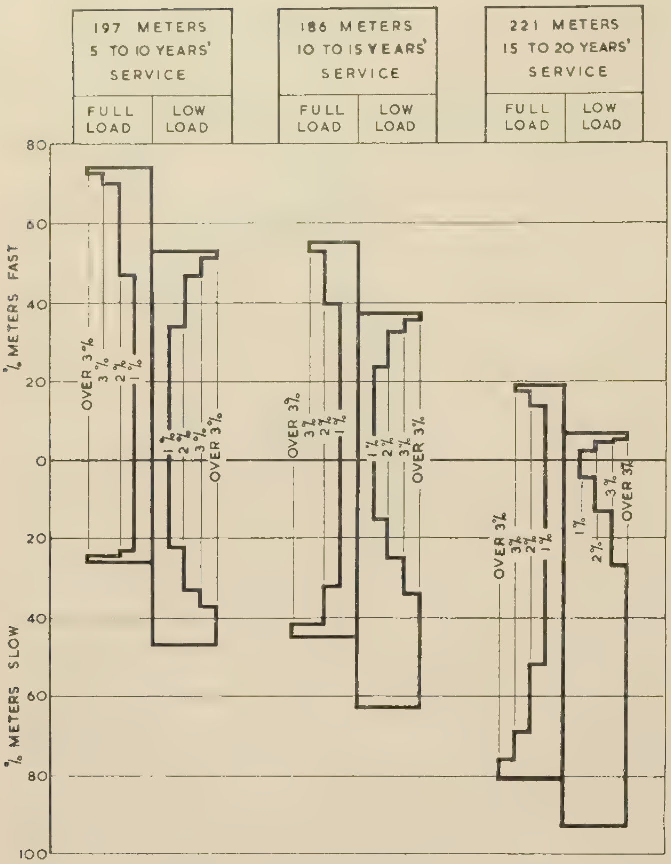

Fig. 3.—Errors of off-circuit meters.

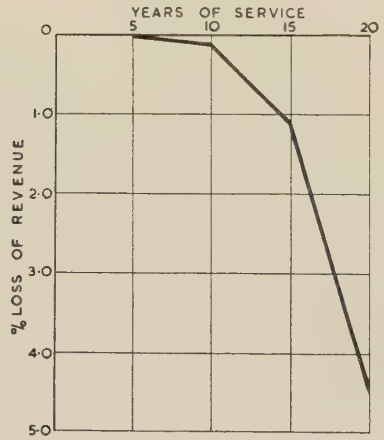

Fig. 4.—Loss of revenue with time for older meters.

Fig. 4 emerges. With such a curve, and knowing the costs of changing and reconditioning meters, the meter engineer can decide when the added costs of loss of revenue, changing and reconditioning will result in the minimum annual cost. In this connection it is regrettable that the cost of changing meters (which varies widely with localities, and is not usually under the meter engineer's control) is from two to five times the reconditioning cost, and this suggests that a plug-in design as used in America might have economic advantages. This is another subject requiring study.

A part of the meter engineer's adequate job where there is scope for the application of ingenuity in reducing costs is that concerned with reconditioning meters. This work is traditionally split into two parts—the mechanical processes of cleaning and replacing worn parts, and the subsequent electrical adjustment and testing.

At present, with a large inheritance of meters of earlier design, the mechanical overhaul is liable to involve considerable expensive hand work. Looking to the future, when sufficient sustained pressure should result in the availability of standardized components, overhauling should require only the simple replacement of parts likely to wear. I shall not say more on this topic, except to put on record that the use of ultrasonically-agitated cleaning baths have, where applicable, been very effective in giving consistently cleaned components in much reduced times. More work is needed, however, to make this method of cleaning applicable to all meter parts.

Remembering that the State requires the recording of actual errors at various test loads, the work of adjustment and testing is best done in two stages. The first is to ensure that all the meters when finally tested will have errors within the acceptable limits. This is readily and quickly accomplished by stroboscopic methods at the higher loads and by a system of slave counters driven in step with the substandard meter when the rotor speed is low and precludes the use of the stroboscope. These methods have been described in detail elsewhere. The second stage, i.e. the determination of the actual errors, is best and most cheaply done either by the slave-counter method or by recovering something from the adversity imposed by legislation and using the electrical-dial test method for all test loads as well as the mandatory one.

It may be of interest to mention here methods devised in London for saving the very considerable time formerly spent in loading large batches of meters on to racks for testing, and connecting them up. The mechanical clamping of the meters to the racks has to be capable of dealing with meters differing widely in height. To accommodate the many types of old meters with non-standard terminal centres, moveable contact pins are used. Finally, to avoid having to disconnect the voltage circuit of each meter from its current circuit and restore this connection after test, a multiple-secondary voltage transformer has been devised. This transformation is included in the measuring circuit, and therefore, to ensure the maximum degree of similarity between secondary windings, these are, in fact, separate wires in a 41-strand cable wound on a toroid core. The reference substandard meter is connected to one secondary, and each meter on test to its own separate winding. The measured differences between secondary windings are of the order of 0·004% of ratio, and 0·8′ of phase angle. Although we, in London, are a little proud of this arrangement, it is to be noted that it would not need to be used at all if electrical dial testing could be dropped.

Using the kind of approach just outlined, the cost of reconditioning a simple meter in London testing stations is now about 14s. 0d. In an inflationary age money comparisons with past costs are meaningless, and so it is perhaps better to record that the productivity per person engaged on meter reconditioning is now 50% higher than it was in 1949. Expressed in other and perhaps more telling words, the adequate job, as outlined, has saved the electricity consumers of London at least £500 000 in eight years, and is producing a markedly better product.

As capital becomes available to scrap and replace the older meters there should be a further improvement. Co-operation by all concerned could make a dramatic change, as in other fields of industry.

I now wish to turn to some interesting experiments which

began as a search for a means of speeding up the testing of sample meters to which I have already referred. If carried out by conventional methods, this is time-consuming, as it involves a very large number of test runs, each of two minutes' duration or more.

The broad aim of the experiment was to find a suitable starting and stopping device actuated by the meter under test so as to count a preset number of its revolutions, as this, by eliminating the variable reaction time of a human observer, would permit of very much shorter test times, and would also improve the precision of testing. This done, it was desired to display the meter's errors in direct-reading form on Dekatron tubes, to avoid the complexity of mechanical counters, and to eliminate calculations.

Photo-electric devices for counting meter revolutions are quite well known, but some preliminary trials of a photo-transistor suggested that it might be more convenient than conventional methods. A photo-transistor pick-off was therefore first constructed for the more difficult duty of deriving a pulsed supply from 100 holes in a disc on the spindle of a rotating substandard meter. It was found highly successful, compared with the more usual photocell, in that a much lower level of light was acceptable, and the circuit design was simplified. The low light level has two advantages. A low-rated exciter lamp can be used, run at low voltage, which extends its life. Also the lamp can be kept outside the meter and so will give rise to no temperature side-effects.

At this stage a digression occurred, because it was realized that the photo-transistor and underrun exciter lamp, with its relatively long life, appeared to be a practicable answer to a long-felt need, namely a frictionless 'contact' device for use with impulsed summation metering equipment.

I should also, perhaps, explain that such metering equipment, which is extensively used for measuring maximum demand on large supplies, requires that the meters involved shall transmit signals to the summating device each time a predetermined amount of energy is registered by them. Photo-electric devices have not previously been used for this purpose because of the relatively short life of the exciter lamp, which must burn continuously.

Judging by the life of similar continuously-burning underrun panel indicating lamps, the proposed photo-transistor 'contact' device should certainly give at least two years' life, and the maintenance required would then only be the unskilled job of lamp changing.

Returning to the main experiments, photo-transistor counting heads were constructed for several types of meter in current use, making use of the small anti-creep holes in the meter discs. The display panel follows conventional lines, and is arranged for simultaneous tests on six sample meters. The meter errors are presented in terms of hundredths of a revolution of the rotating substandard. By including a wattmeter in the test circuit, and holding a steady load thereon, the errors of the rotating substandard can be determined, using the same display tubes, in this case started and stopped by pulses from a standard clock. In this way, the operation of the whole apparatus can be quickly checked at frequent intervals.

This apparatus provided the required means of speeding up the sample testing. For demonstration here it has been slightly rearranged to show counts on six successive revolutions of the same sample meter. This has been done to show the consistency of the equipment.

You will note that the error of the sample at the higher test loads is measured to within one part in one thousand in ten seconds. As at least one revolution of the sample meter must be taken, tests at low loads take up to 75 sec, but I think the claim I made earlier as to the relative speed of the revolution-counting method of testing is justified.

The apparatus as described suffers from a practical defect, however, in that, to use the photo-transistor counting heads, special meter covers are necessary, and also some meters do not have anti-creep holes in their discs. It was therefore decided to try out the possibility of putting a small spot of radioactive material on to the sample meter disc and to try to count revolutions thereby. It was realized that, if this were successful, the method could be applied with considerable time saving to the general testing of meters. There would be no need to remove their covers and they could be tested exactly as they would be used in service. Accurate tests could also easily be made after installation, which would assist investigations of on-service life.

Attempting accurately to detect the passage of a radioactive spot inside a meter was an entirely new field. Some difficulties were foreseen and many others were encountered, but it has been possible to produce and demonstrate a model which works but is obviously capable of much improvement.

Looking to the future, and assuming that the State will one day not require electrical dial tests, nor the recording of every error of every meter at every test load, it is now possible to see the way to a semi-automatic test equipment, which will only require meters to to be continuously put on to it, and removed, and which will indicate by green and red lamps if the meters are adjusted to acceptable accuracy. I suppose that if the amplification were worth while, the equipment could also print out the errors on a tape.

I end, therefore, having established some continuity between the Section's remote past, and the control and nuclear work of the last two Chairman's Addresses.

Remembering my original aim, I hope I have demonstrated that meter engineering can be a fascinating field of work. I have had no time even to mention many interesting aspects, which, with those I have outlined, can usefully employ a young man's whole technical ability. Many of the original meter engineers have moved to other and more lucrative work, but they and those still engaged therein have, I think, never regretted their association with meter engineering.

CENTRE, SUB-CENTRE AND GROUP CHAIRMEN'S ADDRESSES

The Institution of Electrical Engineers
Abstract No. 2470
Feb. 1958
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EAST MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By J. D. PIERCE, Member.

'TWENTY-FIVE YEARS OF DEVELOPMENT OF THE GRID SYSTEM IN THE EAST MIDLANDS'

(ABSTRACT *of Address delivered at* LOUGHBOROUGH, 8*th October*, 1957.)

The author went to the East Midlands 25 years ago, since when he has been closely associated with the Grid system; his Address reviews the developments in the area during the transition from a simple ring with inter-area lines to the highly complex network of to-day.

It quickly became apparent that insulation values were too low for polluted atmospheres, and although insulators were cleaned as often as every three months in dirty areas, flashovers in foggy weather could not be prevented. Tension insulator strings, however, were free from trouble owing to the washing action of rain, and sloping insulators without sheds were then adopted for suspension strings but were later superseded by the present-day anti-fog design. Lantern slides showing the original 9-unit insulators, the sloping anti-dirt type and the present-day anti-fog design with a longer leakage path were exhibited.

To check the performance of insulators in service, live-line testing was evolved; this was illustrated by a film showing the technique employing an electrostatic voltmeter on an insulated stick.

In the early days a close watch was kept on the conductors for vibration, and wherever this was suspected a Vibracorder was clamped to the conductor. This confirmed the existence of vibration, further borne out by cases of broken strands, and Stockbridge dampers were fitted. These are still fitted to both 132 kV and 275 kV lines.

Initially, all mid-span and the majority of anchor clamps were of the cone type. Following failures on the more heavily loaded lines due to the conductor parting some 2 ft from the clamp owing to high resistance, these joints were satisfactorily remade using high-melting-point grease in place of the original bituminous filling. On the outbreak of war there were considerable movements of population and industry, with the immediate result that a system designed primarily for interconnection had to deal with bulk transmission and many circuits had to carry current far in excess of their design figures. The cone-type joints again became the weakest link, and it was essential to replace them with the new compression type, better suited for heavy currents. The author described the difficulties of carrying out this work under war-time conditions, and went on to describe the effects of trailing-cable faults due to barrage balloons and how this work fully absorbed the undertaking's resources. Less urgent work such as routine insulator cleaning was suspended, showing that the additional insulation was satisfactory.

The steel-cored-aluminium conductor originally used, namely 37/·110 in ($0 \cdot 175\,\text{in}^2$ copper equivalent), is still used on most 132 kV lines, but certain heavily loaded lines use 61/·125 in ($0 \cdot 4\,\text{in}^2$ copper equivalent), the latter size being standard for 275 kV lines designed for bulk transmission. The overall application of grease proved to be the best preventive of corrosion due to salt and industrial pollution, but this technique was confined to exceptionally bad areas owing to handling difficulties.

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Suspension strings, which gave trouble in dirty areas, had to be increased from 9 to 12 units, and frequent cleaning of post insulators was necessary. A film of substation live-insulator washing showed the jet emulsifying before hitting live metal, and the operator wearing rubber gloves, with an earthed connection applied to the nozzle. Although this insulator washing has given good results, the practice has not been extended, and the present tendency is to use insulators incorporating an oil bath. Alternatively a coating of suitable grease may be applied to the insulators.

The original 132 kV oil circuit-breakers had plain breaks, without any arc-control devices, and large contact surfaces at comparatively low contact pressures. When these breakers opened under fault conditions the oil became so heavily carbonized that it was necessary to take the breaker out of service to prevent internal flashover. The contacts usually required attention and the tanks flushing and refilling with clean oil. About 1 100 gal of oil per phase were required, and enough clean oil was available on site to deal with a 3-phase breaker, the dirty oil being purified and stored. A further hazard was due to explosive gases seeping to the mechanism box and being ignited by a spark. Before the war, modernizing the 132 kV circuit-breakers was commenced by fitting candlestick-type high-pressure contacts and arc-control devices, and speeding up the operating gear. This greatly reduced the contact burning and oil carbonization, enabling the breaker to remain in service after clearing faults. Further modifications have since been carried out, uprating the original breakers to 2 500 MVA breaking capacity, and now 3 500 MVA breakers are being installed where necessary. Both solenoid and pneumatically operated mechanisms are employed.

Recently a 132 kV small-oil-volume circuit-breaker has been installed, and the author described its advantages and disadvantages. 132 kV air-blast switchgear is also in general use, but only at larger switching stations adjacent to power stations, as noise could be a nuisance in residential areas.

The 132 kV isolators have given excellent service, and the present-day designs differ little from those installed 25 years ago, apart from the use of motorized mechanisms at certain key points.

On transformers many developments have taken place in the layout of the tap change, especially with regard to selector switches, which on modern transformers are in separate tanks. This avoids the necessity for frequent entry into the main tank. Many large transformers of 60 MVA are designed so that they can travel within rail loading gauge, complete with tap-change gear. When the original Grid substations were built great importance was attached to rail access. The development of road transport vehicles for these heavy loads has been such that transformers are now delivered by road wherever possible, and a slide was shown of a 120 MVA 275/132 kV auto-transformer on one of these modern road vhicles.

The original lattice-steel-structure substations have been super-

seded by the layouts using standardized ferroconcrete structures. This has eliminated the necessity for painting.

The double-busbar layout is retained for important switching stations, a recent development being a reserve busbar in the form of a U with the main busbar inside. At Castle Donington, where the busbars are in three sections, the centre-section reserve busbar is cabled to avoid crossing the main busbar. Restrictions in capital expenditure have tended to eliminate 132 kV circuit-breakers at receiving stations fed by two transformer feeders, and in the event of a fault in the transformer zone the remote oil circuit-breaker is intertripped by 132 kV fault-throwing switches earthing one phase or over G.P.O. pilot wires.

Slides of the various types of substation were shown, and the modes of operation of 'three-switch', 'single-switch' and 'mesh' substations were described.

Originally the control of 132 kV circuits was carried out from the adjacent power station, and the author described the robot form of control recently installed at an unmanned single-switch substation which automatically isolates a faulty transformer and returns sound equipment to service.

Much greater use is now being made of 132 kV cable on line terminations (in some cases the sealing ends are mounted on the tower) and on 132 kV generator connections to avoid crossing other circuits. Cabling of intermediate sections of overhead lines is avoided as far as possible owing to protection difficulties.

At the C.E.A. 275 kV cable testing station at Staythorpe the Cable Makers Association installed in 1954 four different types of 275 kV cable in order that experience could be obtained under actual operating conditions.

It is proposed to use 275 kV cable to connect all four generators at a new station in the East Midlands.

The selection of a route for an overhead line is an extremely difficult and complex matter, and whereas 25 years ago a route would be based primarily on the best one from an engineering point of view, many other factors now enter into the matter. Apart from the necessity of avoiding built-up areas, the agreement of numerous Government and local government authorities, and possibly other interested bodies, must be obtained.

Aerodromes are a major difficulty, as it becomes very difficult to avoid the flight funnel, where, owing to the angle of approach, it may be necessary to erect 275 kV towers at least $2\frac{1}{2}$ miles from the end of the runway. Another very real difficulty is land earmarked for open-cast working of coal or iron-stone, as it is quite impossible to cross the site with an overhead power line. In view of these difficulties, considerable time may be spent in finalizing a route and it becomes increasingly urgent to start construction in order to meet the required commissioning date. On the other hand, construction cannot start until wayleaves have been granted for which tower positions are necessary. In order not to have to wait for a profile prepared from a ground survey, an aerial survey is often carried out, as soon as the route is finalized. From the contoured maps provided to a scale of 1 : 5000 with 5 ft contours, a profile is prepared and tower positions are plotted, and this is generally accurate enough for wayleave purposes. The saving in time may more than offset the cost of an additional tower extension here and there.

In 1952 the first 275 kV line in this country was commissioned, initially at 132 kV as the terminal equipment and transformers were not complete. This single-circuit line is between Staythorpe and West Melton near Rotherham and is carried on Y-shaped towers, which will not be repeated as double-circuit towers are now used and if only one circuit is required only one side is strung. The use of twin conductors means that great care has to be taken in erection and sagging, as the slightest irregularity is made more noticeable by the spacers. To facilitate final adjustments, sag adjuster plates are fitted in the tension sets.

A film was shown of the phenomenon of conductor clashing, which damages the conductors; it is possible that as a result of the information gained from this film the decision was taken to decrease the distance between the spacers to 250 ft. Apart from the Staythorpe–West Melton line, to which reference has just been made, and on which twin $0\cdot175\,\text{in}^2$ conductors were used, all other 275 kV lines in the East Midlands are of the heavy duty-type using twin $0\cdot4\,\text{in}^2$ (61/·125 in) conductors carried on double-circuit towers designed for 380 kV ultimate working. The major difficulty in constructing these lines was the erection of these heavy conductors, great care having to be taken to avoid damaging them. A slide was shown of live-line scaffolding, over a 132 kV line, which is necessary owing to the time taken to run out and clamp in a section over obstacles such as power lines or railway crossings.

It is, of course, a regular practice to carry out maintenance and repairs on one circuit of a double-circuit line with the other circuit alive, and the whole system is designed on that basis. The circuit is properly earthed at the point of work in addition to the earth links being closed at both ends, and a film was shown of the arc drawn when opening the last earth link on such a line on which men had been working.

To date the 275 kV system has operated quite satisfactorily, and there is little to comment upon except to say that faults due to lightning have been more frequent than was expected. It was anticipated that the increased insulation of the line would have reduced lightning faults, but the extra height of the towers coupled with their high surge impedance has counteracted this.

A feature of the 275 kV switching stations is their enormous size; a substation controlling 20 circuits will be approximately 1 100 ft long and 450 ft wide, and it is no easy matter to obtain a suitable site having regard to the ease of connecting generators and line entries.

All 275 kV isolators are motor operated, although manual operation is retained on the earth links. Owing to the height of the insulators the attachment of temporary earths is difficult and special portable earthing equipment has been designed.

The 7 500 MVA circuit-breakers are of the bulk-oil-volume type using 2 400 gal of oil per phase with four resistance-switch breaks in series, and air-blast types with eight interrupter heads per phase operated by air at $325\,\text{lb/in}^2$.

At the time of preparing the Address, no double-wound transformers were in service, auto-transformers of 120 MVA capacity being used for interconnection with the 132 kV system.

Two types of tap changers are in use. One is of the conventional pattern operating at comparatively low voltage at the neutral end. The other operates at 132 kV and the selectors and diverter switches have to be insulated to operate at that voltage. The diverter switches at the top of the 132 kV bushings were shown on a slide.

The main feature of the 275 kV system is the massive nature of all the equipment compared with 132 kV and lower voltages. Insulators, bushings and fittings such as arcing rings, etc., all dwarf equipment used on the 132 kV system and need correspondingly heavier tackle to handle them, as was illustrated by a slide showing a 275 kV transformer bushing about to be lifted into position.

Speaking of the immediate future, the author said that efforts would be made to complete the 275 kV Supergrid as illustrated, and he expressed the opinion that the next major transmission development would be the uprating of a suitable section of the Supergrid for experimental working at 380 kV.

In conclusion the author expressed his thanks to the Central Electricity Authority for permission to give the Address, and also to his colleagues in the East Midlands Division for their help in preparing the numerous films, slides, and photographs.

The Institution of Electrical Engineers
Abstract No. 2539
Feb. 1958

MERSEY AND NORTH WALES CENTRE: CHAIRMAN'S ADDRESS

By T. MAKIN, Member.

'THE DEVELOPMENT OF ELECTRICAL SERVICES IN A SOAP AND CHEMICALS FACTORY'

(ABSTRACT *of Address delivered at* LIVERPOOL, *7th October*, 1957.)

The factory is situated in Warrington and covers an area of 45 acres. Excluding internal rail sidings, roads and the stretch of the River Mersey which the factory bestrides, the total floor area devoted to manufacture is approximately 27 acres. Because, at this point, the river was formerly the boundary between Lancashire and Cheshire, the areas north and south of the river are referred to as the Lancashire and Cheshire factories respectively.

Production of soap started in 1815, and since then other products have been introduced until at the present time manufacturing operations include the production of soap and synthetic detergents for domestic, industrial and agricultural uses; refined glycerine, a wide range of chemicals based on silicate, synthetic fluid catalyst and the refining and hardening of edible oils and fats.

Electricity was first used in 1900, when a 15 kW 230-volt d.c. gas-engine-driven generator was installed to supply carbon-filament lamps. Since then many changes in supply plant have been required, involving the addition between 1903 and 1913 of a number of steam-engine or turbine-driven d.c. generators of outputs ranging from 190 to 500 kW, until in 1917 a turbine plant of 3 000 kVA capacity generating at 500 volts, 3 phase, 50 c/s, was commissioned. This plant, of two 1 500 kVA units, was enlarged in 1922 by the addition of another 1 500 kVA unit and remained in continuous operation until a public supply at 6 kV was introduced in 1940. The turbine plant was maintained but not used during 1940–45, and was utilized for peak-load generation during the winter load-shedding periods of 1947–53, and was finally scrapped in 1955.

Direct-current equipment only was in use between 1900 and 1911; both direct- and alternating-current equipment were used between 1911 and 1952, and at the present time all equipment is of the alternating-current type. A motor-generator was used between 1911 and 1917 to supply alternating current to the Cheshire factory, and from 1917 until 1928 the machine was used in reverse occasionally to provide a 230-volt d.c. supply from the factory 500-volt 3-phase 50 c/s system. Two rotary convertors, each of 500 kW output, were used to supply 230-volt d.c. requirements between 1917 and 1952. Between 1947 and 1952 the d.c. installations were replaced by a.c. equipment.

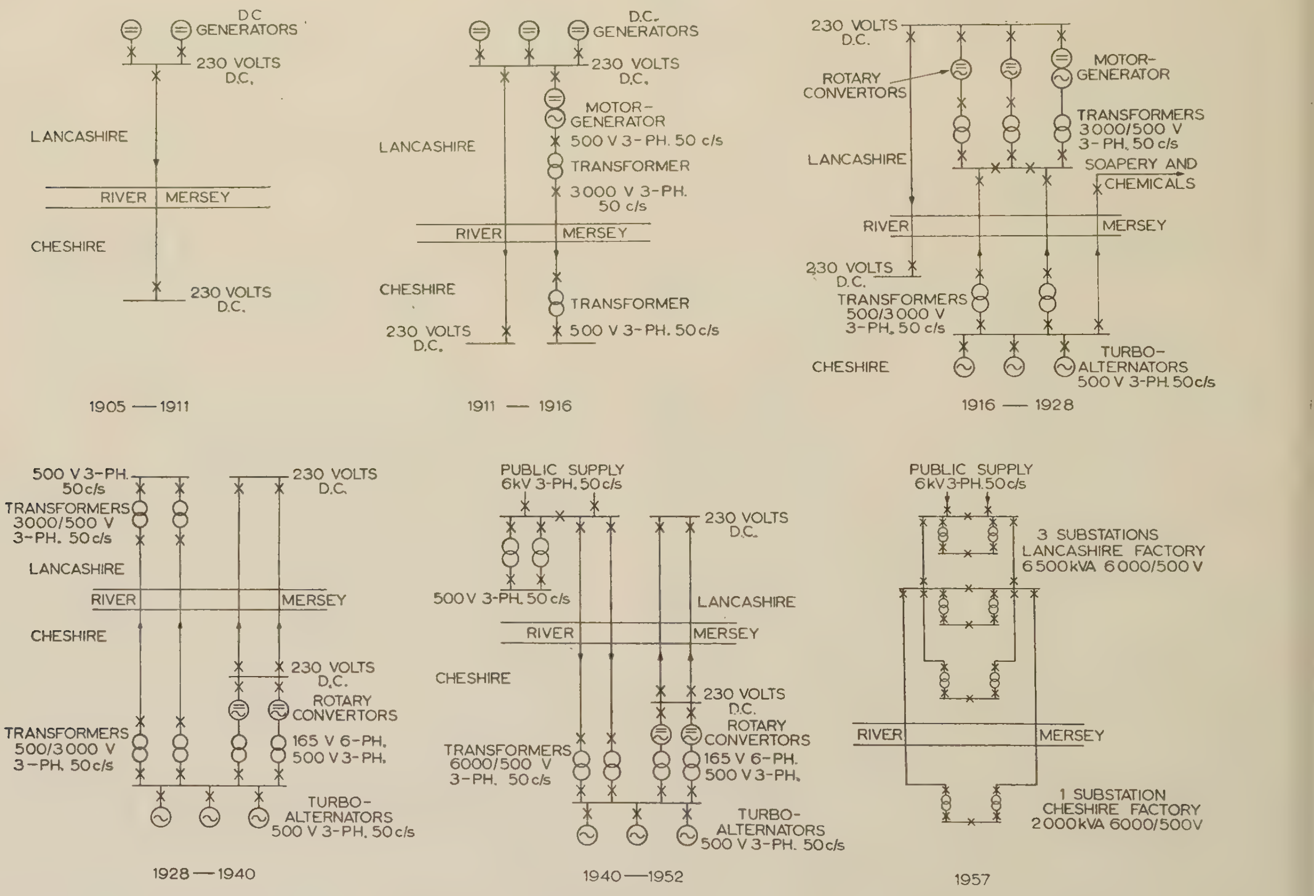

Fig. 1

Mr. Makin is with Joseph Crosfield and Sons, Ltd.

Electric service cables cross the River Mersey on a suspension bridge formerly used as a lifting and traversing goods transporter.

Many changes in major distribution have occurred to cater for the developments in electrical installations required for factory extensions and increased production. At the present time a public supply at 6 kV caters for the factory requirements via four transformer substations; motive-power distribution is at 500 volts, 3 phase, 3 wire, and seven small substations, ranging in size between 200 and 400 kVA and transforming from 500 to 415 volts, provide the 415-volt, 3-phase and neutral services for lighting and heating.

Between 1900 and 1956 the energy used increased from 3 000 to 26 million kWh per year, with a corresponding change in the average cost per unit of 0·5 to 1·11d. The present-day maximum demand is 5 025 kW.

Power-factor correction, by means of capacitors, was introduced in 1935, when 525 kVAr of equipment was installed, which during the past twenty years has increased to 2 020 kVAr.

Beginning with 17 electric motors installed in 1903, the number now in use is 1 720, representing a total connected equipment of 14 000 h.p. The total connected equipment for lighting and heating increased from 15 to 2 500 kW between 1900 and the end of 1956. During the past sixteen years, the accepted increased standards of lighting, together with factory developments, required the addition of approximately 4 000 lighting points.

Table 1 indicates, in ten-year intervals, the developments briefly described in the foregoing, and Fig. 1 shows some of the major changes in both power-plant and distribution layouts.

Table 1

Service	Year						
	1900	1910	1920	1930	1940	1950	1956
Private generating plant, kVA	15	1 500	3 750	4 500			
Private generating plant: average cost per unit, d.		0·5	0·8	0·99			
Public supply: consumers' transformer capacity, kVA					4 000	6 500	8 500
Public supply: average cost per unit, d.					0·7	0·67	1·11
Annual load factors, %		38	38	55	58	59	60
Maximum demand, kW	15	600	1 500	2 000	2 200	3 000	5 000
Energy used per annum, millions of kWh	0·003	2·0	5·0	9·6	11·2	15·75	26·2
Total connected equipment, kW	15	1 100	2 250	3 250	4 250	7 750	13 000
Peak load power factor			0·8	0·8	0·95	0·95	0·94
Total power-factor correction, kVAr					525	1 200	2 020
Total connected power equipment, kW		1 000	1 950	2 750	3 650	6 650	10 500
Number of motors connected		80	150	500	800	1 120	1 760
Total connected lighting and heating equipment, kW	15	100	300	500	600	1 100	2 500
Number of lighting points	100	200	850	1 500	2 000	4 500	6 000
Connected horse-power per employee		0·7	0·77	1·6	2·75	4·2	7·0

The Institution of Electrical Engineers
Abstract No. 2526
Feb. 1958

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By J. F. WRIGHT, A.M.I.Mech.E., Member.

'THE CHANGING PATTERN OF ELECTRICITY DISTRIBUTION'

(Abstract *of Address delivered at* Cardiff, 14*th October*, 1957.)

When the electricity supply industry was nationalized on the 1st April, 1948, much of the distribution network taken over was in urgent need of reinforcement as a result of the war-time ban on this work and poor design and neglect on the part of many of the former undertakings. At the same time there were exceptional demands for increased supplies of electricity to meet the needs of the post-war housing programme and industrial development. The fact that distribution undertakings have had to reinforce and extend their networks to cover these needs during a period when the available capital has been severely restricted by Government control has forced the supply industry to carry out an intensive and critical survey of its former practice, and as a consequence to introduce many changes in distribution.

Growth of Load.—The consumption of electricity in Great Britain is being doubled about every nine years and there are no signs of saturation being approached. Expanding industrial use and the increasing use of electrical heating will undoubtedly maintain this growth for many years. The high rate of load growth has made it difficult for distribution engineers to carry out the necessary work with the limited capital available, but in spite of this it has been thought desirable to plan system extension and reinforcement to meet larger demands per consumer than was common in the past so as to avoid wasteful future capital expenditure on further reinforcement.

The sharp increase in the price of conductors in the post-war period has profoundly affected distribution design by encouraging the use of higher voltages and shorter l.v. distributors of small conductor section.

Bulk Supply Points.—Policy governing the development of the Grid system prior to nationalization severely limited the number of supply points to distribution systems, with the consequence that each point tended to be over-large and important. This

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resulted in much uneconomic distribution to large areas at comparatively low voltages. Change of policy since nationalization has enabled Grid supply points to be established for distribution wherever this can be proved to produce overall economy; thus the 132 kV Grid is being increasingly used for h.v. distribution.

Grid substations for distribution have been cheapened and simplified by the use of single-switch layouts on the 132 kV side with the development of 132 kV fault-throwing switches for inter-tripping. Wood-pole lines have also been used for distribution as a cheaper alternative to the conventional 132 kV steel-tower lines.

Primary Distribution.—To secure the most economic use of conductor materials, much more use is now made of 33 and 66 kV mains for distribution, and the present trend is for primary substations to be so closely spaced that the mains operating at the lower high-voltages can be reduced to radials or non-automatically-switched rings of minor individual importance.

Wood-pole lines of simple unearthed construction employing horizontal conductor formation are now practically universal, and for sheltered routes single-pole construction employing line-post insulators has proved adequate for 33 kV. Aluminium conductors have been increasingly used as a cheaper alternative to copper for overhead lines. Although 66 kV cables are invariably of the oil-filled or gas-pressure types, it is usual for 33 kV cables to be of normal solid construction. Accessories for oil-filled and gas-pressure cables have been progressively simplified and cheapened, and the introduction of aluminium as a sheathing material has eliminated the need for the expensive external reinforcement required by lead sheaths used under conditions of internal pressure. These changes now sometimes result in oil-filled and gas-pressure cables being cheaper than solid cables for 33 kV when their higher current-carrying capacity is of advantage.

There has been much detail improvement in plant for 66 and 33 kV substations leading to lower maintenance costs and increased reliability. 33 kV outdoor air-insulated metalclad package-type switchgear has been developed recently and has proved to be a satisfactory and cheaper alternative to conventional metalclad switchgear housed in a brick building for sites where space is restricted. One of its outstanding advantages is the short time required for erection.

Increasing fault levels have directed more attention to the use of higher-speed protective systems to limit the damage caused by fault current. Pilot-wire protective schemes are increasingly used on underground feeders, and new types of aerial pilot cables have been made available for use with overhead feeders. Impedance protection has been developed suitable for use with short overhead feeders at a price permitting its use for distribution work. Busbar protection is being more frequently used on primary substation switchgear to limit persistent damage in the event of a fault.

11 kV Distribution.—There is a marked tendency to standardize the voltage for feeding distribution transformers at 11 kV, and many h.v. mains originally installed for operating at lower voltages have been successfully upgraded to 11 kV working. Before upgrading cables to 11 kV, I normally have the feeder rejointed to 11 kV standards and then pressure tested at 35 kV d.c. between cores and from cores to earth for 5 minutes. The 11 kV overhead lines are now normally constructed to B.S. 1320 for conductors up to $0 \cdot 05\,\text{in}^2$ and to a similar design for larger conductors. These simple lines are cheap and reasonably inconspicuous, and they give little trouble in service. Relaxation of Post Office regulations now permits the use of p.v.c.-insulated conductors for Post Office crossings instead of expensive and unsightly cradle guards. Pole-line construction has been much cheapened in recent years by the use of mechanical plant for construction and the development of simple line fittings which can be erected speedily.

Aluminium conductors have been used extensively by some Area Boards in underground cables as a cheaper alternative to copper, but recent reductions in the price of copper have eliminated much of the saving that could have been made two years ago. While considerable advances have been made in the soldering of aluminium conductors, this still requires a higher temperature and a more chemically active flux than with copper soldering, and this possibly increases the risk of damage to insulation during jointing.

Circumstances have forced a great reduction in l.v. feeding distances, and this has resulted in a sharp increase in the number of distribution substations required, so that costs per substation have had to be much reduced. Brick-built substations are now used as infrequently as possible, and most distribution substations constructed in built-up areas are of the outdoor ground-mounted type. As transformer faults rarely occur, it is now usual to control the h.v. side of distribution transformers with a non-automatic oil switch and to leave faults to be cleared by the automatic 11 kV feeder circuit-breaker, which may cover several distribution substations. The 11 kV switchgear at outdoor distribution substations therefore usually consists of three non-automatic oil switches of the fault-making load-breaking type to control the two 11 kV feeders and the transformer. Progress in distribution transformer standardization now enables standard control equipment to be mounted on the transformer cable-box flanges.

In rural areas, scattered communities are now usually supplied by taking the 11 kV line close to each of the consumers' premises and providing one transformer per consumer, with the l.v. lines limited to services. The development of 11 kV high-speed reclosers has contributed to reliability of supply in rural areas, but their use is often limited by their low breaking capacity of 50 MVA 3-phase.

Distribution economy and efficiency require that substations should be properly sited, but this can often be done only if interference with amenities is minimized. The appearance of substations requires careful attention, and because, with the small l.v. feeding distances, it is unavoidable that transformers should be sited close to residential property, transformer hum must be considered. Manufacturers should pay more attention to this matter.

L.V. Distribution.—With the smaller feeding areas from distribution substations, l.v. mains sizes have been substantially reduced in spite of the fact that new distribution systems for domestic areas are being designed on the basis of 3 kW a.d.m.d. per consumer.

Economic circumstances have reduced the use of l.v. interconnection between substations, and some Area Boards are providing no l.v. interconnection for residential distribution systems. The absence of interconnection makes the maintenance of substations difficult as it involves planned interruption of supply to consumers. The use of mobile generators to maintain supplies during substation maintenance has been tried, but it is not a universal answer and it appears that there may be a case for limited l.v. interconnection.

System Operation.—The increased size of distribution undertakings since nationalization has favoured the use of a centralized control system with shift control engineers superintending all switching and other operation of the h.v. network from their control room. Communication between the control room and the staff in the field has been enormously improved by the use of mobile v.h.f. radio. Supervisory control is being increasingly used in connection with primary substations to eliminate the high cost of substation manning.

Mains Testing.—The larger distribution systems now in being justify the setting up of specialized mains testing departments responsible for all h.v. fault localization and testing. Specialized engineers covering large areas carry out sufficient fault localization work to become very skilled, with the result that they locate the faults more accurately and in a shorter time. With a centralized fault location service the test engineers may be lavishly equipped, so that their test vans contain all that is necessary to deal with any type of fault. There have been many improvements in mains testing equipment in recent years.

Conclusion.—Many changes have been brought about in distribution practice during recent years as a result of efforts to improve and to reduce the cost of electricity distribution. With the increasing demand for electricity, there is bound to be an increasing demand for capital to develop distribution networks, and this will no doubt act as the spur to bring about many more changes in distribution practice in the years to come.

The Institution of Electrical Engineers
Abstract No. 2489
Feb. 1958

WESTERN SUPPLY GROUP: CHAIRMAN'S ADDRESS

By C. W. A. PRIEST, B.Sc.(Eng.), Member.

'NEW POWER STATIONS IN SOUTH WALES'

(ABSTRACT *of Address delivered at* CARDIFF, 21*st October*, 1957.)

The Address deals with some of the more unusual problems and techniques arising in the design and construction of five new power stations in South Wales.

At Aberthaw, rock of great depth and strength underlay the site, covered with some 20 ft of sand and clay, and the station is founded on the rock with a retaining wall providing a basement. The foundations at Rogerstone were perhaps even more interesting in that there is rock about 40 ft down but the overlying land was covered with large boulders. The Benoto system of piling was adopted, in which well-boring technique is applied to the making of piles a metre in diameter.

The cooling-water problem at Uskmouth is one of very dirty water conditions at low tide, together with a tidal variation of about 42 ft. The circulating water outlet has been deliberately exhausted upstream of the inlet in order to augment water supplies at low water, and the problem of obtaining water is largely one of cleansing the intake screens during low spring tides. At Rogerstone, make-up water to the cooling towers is taken from the River Ebbw, which is extremely dirty with solids in suspension and some trade wastes; at times the water is distinctly acid. The make-up is therefore treated through a filtration and settlement plant before passing to the cooling towers. An automatic pH recorder has been installed to provide an automatic shut-down of the river intake pumps when the river becomes acid.

At Aberthaw the water is to be taken from a point about half a mile offshore. To this end a 95 ft circular concrete caisson is being constructed onshore above the high tide mark, and when complete and sealed will be launched 'Mulberry' fashion, towed out to sea, and sunk on the prepared section of rock. The circulating water tunnels now being driven from the shore will connect to the inside of this caisson.

Mr. Priest is with the Central Electricity Authority (South Wales Division).

The Rogerstone station has been clad in aluminium sheeting, and aluminium will also be used for the cladding of some of the coal conveyors at Aberthaw.

The 60 MW stators for Rogerstone were sent by sea to Cardiff from Newcastle. They were lifted out of the ship's hold by means of a 100 ton floating crane and put on to heavy loading trucks for transport to the station. Here, instead of the usual engine room crane there is a single light duty crane, and demountable gantries were provided for lifting the stator off the road transport on to the foundation block.

With the 2-set station at Rogerstone a single control room midway between boilers and turbines on the operating floor level has been provided, and in this control room are housed operating instruments and mechanism for both turbines, both boilers and all electric switchgear. There is no separate electrical control room.

At the later stations it has been decided to handle dust by the pneumatic system and to deliver it into hoppers still dry. This will enable users of fly ash for brick making and for concrete substitute to have the ash in the form in which they desire it, wet or dry; it will also enable the fly ash to be loaded into lorries for filling in waste land if that be the disposal method. At Uskmouth 'B' and at Aberthaw the furnace ash will be handled to points outside the station by hydro-ejectors rather than pumps.

One interesting electrical point can be mentioned. A 4 000 amp switch is to be inserted between the alternator and the step-up transformer of three of the generators at Uskmouth 'A' in order that these machines can feed a different 132 kV system from the rest—a connection which avoids additional complications of house transformers and auxiliary synchronizing. The 4 000 amp oil circuit-breaker will be used for synchronizing only after the auxiliaries have been energized through the main step-up transformer from the 132 kV busbars. All fault clearance will operate the 132 kV switch.

The Institution of Electrical Engineers
Abstract No. 2506
Jan. 1958

SOUTHERN CENTRE: CHAIRMAN'S ADDRESS

By L. G. A. SIMS, D.Sc., Ph.D., Member.

'NOT WITHOUT HONOUR—A CONTEMPLATION OF UNIVERSITY, COLLEGE OF TECHNOLOGY AND STUDENT MEMBERS'

(ABSTRACT *of Address delivered at* PORTSMOUTH, *2nd October*, 1957.)

I should like to use for my Address the theme of engineering education and to review the functions of university and technical college as they appear after a period of renewed evolution. There are now the new Colleges of Advanced Technology, with their six-month sandwich diploma courses, and the new Regional Colleges of Technology. These represent changes in the picture of higher education and perhaps call for some re-appraisal of position by university applied science departments.

In speculating upon future university developments, I must make it clear that no official university policy is implied by my suggestions.

A successful approach to communication, to the teaching of students, is to work almost exclusively in contact with them. This makes the teacher an artist in the interpretation of syllabuses and regulations, both of his own college and of the many external examining bodies. My thoughts are with numerous past and present colleagues whose teaching abilities justify that description. Some of the colleges whose routine is served best by this system have now been promoted to overcome the nation's present shortage of technologists. These are the new Colleges of Advanced Technology. There are also the newly-termed Regional Colleges of Technology, and finally there are the general technical colleges, some of which are large, with modern buildings, and with good staffs and equipment.

In all these colleges the emphasis is upon teaching, though not to the exclusion of research. The banner of their pride wears the legend: 'This communication of knowledge is important.'

In the universities the authorities place emphasis upon residence and research. This means both experimental research and research which is concerned with reading and the exercise of the mind. These forms are needed if some university students are to be inspired by professors, lecturers and tutors to ascend to the highest peaks of thought, to discern new lands and to write their names later as discoverers in the long story of man's achievement. We think, therefore, that every university engineer-teacher should spend appreciable time upon scholarly pursuits, including study abroad, and that he should be provided with modern equipment and with extensive library facilities. His work should be 'predominantly intellectual and varied'. The distinguished academic colleagues with whom I have worked, and still have the pleasure to work, would endorse that opinion. An atmosphere is provided thereby which lies about the student and subtly enables him to unfold, develop and flourish.

University academic staff exercise the privilege of entrusting research projects to the hands of their graduates, sometimes under Government contract, and of recommending those graduates, when successful, for research degrees (also called higher degrees).

In the university itself and in its halls of residence, engineer-graduates and undergraduates enjoy the company and ideas of students from other faculties, such as those of science, arts, theology, economics and law. But student social life to-day is less exclusive to universities than was formerly the case, due to the growing residential aspect of other colleges, and indeed not only to that. Most large engineering firms have taken over fine old country houses as residences for their various grades of apprentice. Names such as Coombe Abbey, Coton House and Castle Bromwich Hall come to mind. In fact the engineering industry is housing its young people not only in hostels and halls of residence but in the stately homes of England.

Sandwich Courses in Electrical Engineering.—There is now a form of entrance to Southampton University and its electrical engineering courses, called the thick sandwich or 1–3–1 scheme, in which combined studies are made available by the University and various branches of industry. It combines academic education with industrial training. One superimposes this scheme upon the University's traditional pattern of education for electrical engineers by giving the sandwich a thick filling which is in fact the full-time three-year degree course. We adopt and adapt earlier systems (consisting, for instance, of a vacation year in industry between school and the University) and make of them a complete five-year course of education and training. Variations of the 1–3–1 scheme are possible, without disturbing fundamentally the timetable routine of the University. The training curricula of these sandwich courses are at present wholly in the hands of our industrial friends.

This development in combined university education and electrical works-training is now on trial, and it is early to judge its results against those of the direct-entry system. We expect that the latter will always be required, because enlightened industry looks for a certain number of young graduates who will challenge current works procedure and desire to introduce new ideas. That is presumably most likely to happen with a few of the more gifted direct-entry graduates, because they will not have experienced any previous industrial influence.

On the other hand, I have heard a leader in industry state fairly recently, and repeat, that he prefers young men who are primarily works apprentices, who have gained their academic engineering education concurrently by some form of part-time study.

It is assumed that university sandwich courses improve upon that point of view, even though not complying literally with it.

University and industry at present fix their own curricula for such courses independently, the one in education, the other in training, but it may prove advantageous, at some future time, to introduce a measure of joint consultation. In the meantime, industry gives encouragement to the university sandwich experiments and has proved eager to help, whenever and wherever consulted. Joint consultation between university and industry could open wider the door to co-operation between firms, in the national interest, and to inter-firm student training, where that is desirable. Southampton University, on its part, already shows its keen interest in the students during their works training, by tutorial visits.

We have also a means of entry for the best examinees amongst young men after success in H.M. Dockyard Schools examinations or after their Ordinary National Certificate year. It is called 'industrial entry'. It meets the needs of those who have not come solely by 'A' level results in the G.C.E. examinations.

The Arts Graduate in Industry.—It is important that the returns for 1955–56 of the University Grants Committee if a (recent

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statement about them has been interpreted correctly) show 13% of all university students as occupied in the arts, against 21% in the pure sciences and only 13% in the technologies.[1] Clearly there is room for a point of view in which industry employs arts graduates.

The picture of a place in industry for the arts graduate is illuminated by information supplied by a works education and training department, about some of their arts recruits, who, it is stated, start work in the training drawing office and training workshop. After the first six months they go into departments dealing with organization of various types, but factory departments are not likely to form a very significant part of the training. They have the opportunity of studying one day a week to give them some scientific background, 'but there is no intention whatever of turning them into engineers'.

Nevertheless, it could hardly be regarded with equanimity if young non-engineering people entering engineering firms and not carrying any direct engineering responsibility should gravitate —or levitate—into many of the senior administrative posts. There is perhaps a tendency to regard an arts education as suiting a man for government and a science education as fitting the other man for the back room only.[2]

History and Philosophy of Science in Engineering Courses.—Perhaps one may refer briefly to the inclusion of some study of the philosophy of life and nature in engineering teaching.

The best time to inculcate the idea of a 'wisdom of the past' in the mind of the young engineer is during his schooldays, and a broad thread of historic and humanistic outlook should continue thereafter during his university career. It is for that reason that a close tie with classical physics as well as with modern physics is desirable at the university. This can be accomplished by introducing a special subject, called, for instance, 'history of science'.[3,4] But experience makes me doubt whether it is attractive to students and, if not, whether it can be wholly successful. On the other hand, a well-conceived course of study in the broad field of physical-engineering measurement provides an opportunity of discussing the pioneer work in physics and engineering and the personalities of the pioneers, many of whom were great characters. In addition, it continues the fundamental electricity and magnetism and is appropriate to all electrical engineering students. Good students re-live in their own laboratories some of the difficulties and triumphs which men like Kelvin, Clerk Maxwell, Latimer Clark, and other intellectual scientists of the nineteenth century experienced when establishing the theory and practice of accurate electrical measurement. Precise measurement in engineering is remarkably stimulating and self-rewarding to students and represents in their minds an approach to ultimate perfection.

Longer Engineering Courses.—In face of the advancing front of scientific knowledge the academician to-day finds it a great question how much he should attempt to impart to engineering students in a three-year university course. It may well be that the limits of the present three-year courses have already been reached, although a device exists, a palliative, used in the engineering courses at Southampton and elsewhere, namely that of dividing the engineering course into fast and slow courses at the end of a common first year. The fast course reaches honours standard in three years and the slow course is of the same duration but has less academic content and is for students of average ability. It leads to an ordinary pass degree and has an advantage in that more time is available for class exercises and examples.

In electrical engineering it is at least debatable whether the fast honours course, though well-conceived originally, still covers sufficient ground to prepare university honours students for the more recent forms of modern industry.

Another palliative is to emphasize certain electrical subjects more than others, by subdividing the honours men into two streams, for example those who select power studies and those who prefer electronics.

Now subdivision of electrical engineering instruction should only be carried a short distance, at least in a university of moderate size, and I should therefore like to make the perhaps unexpected suggestion that still larger first-year university engineering classes should be contemplated.

At the end of the first university year, it would be assumed that examination results then gave a true picture of the developed schoolboy, and the universities could divide the first-year group into two or more sections, selected upon examination marks. It would be easy to say that this procedure would divide the men into sheep and goats, but that phrase is no longer considered to be realistic. The goats are no longer unutterable, but represent valuable junior engineer personnel whose abilities are matched to some other form of engineering education, perhaps to the three-subject curricula of the National Certificate schemes, beginning perhaps at the A.1 stage and finishing with a Higher National Certificate. The further goal of Part III of the new Institution Examination, with Associate Membership to follow, should be regarded as attainable by the best of these students. This principle of dealing with the lower-half groups amounts to limiting the range of studies but maintaining a high standard.

We have considered 'fast' and 'slow' courses. The logic of developments, having regard to the present state of scientific knowledge, is to consider 'long' courses. These could be basically of two forms, the first an extension of the present three-year honours course, through what is now known as post-graduate study. For these developments, some temporary industrial restraint in recruitment and some industrial finance might be needed.

British long courses of four, eventually of four and a half or even five years' duration, could excel the engineer-diploma courses of the Continent. But only those students who proved themselves able enough academically to benefit from the long courses fully would be drafted into such advanced studies.

The Master of Science Degree.—The custom in British universities hitherto has been to set the three-year graduate or bachelor, who is seeking a year's further study, an experimental problem in which both theory and experiment are involved. This Master of Science course includes staff supervision but probably no lectures, over a period of at least one year, but latterly the inducements offered by industry have taken away most young graduates at the first-degree stage: in many cases this is to be deplored. A revival and some further development in the M.Sc. form of study for fourth-year engineer students is desirable. For many university students it is still a good finish to their academic work and it does not keep them too long from industry.

But new 'long' courses reaching the present post-graduate theoretical levels of the largest engineering schools should also become a regular part of all university engineering education.

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The Institution of Electrical Engineers
Abstract No. 2491
Jan. 1958

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By E. OPENSHAW TAYLOR, B.Sc., F.R.S.E., Member.

'SCOTTISH ENGINEERS AND THE SCOTTISH ELECTRICAL TRAINING SCHEME'

(ABSTRACT *of Address delivered before the* SOUTH-EAST SCOTLAND SUB-CENTRE *at* EDINBURGH 1*st October, the* SOUTH-WEST SCOTLAND SUB-CENTRE *at* GLASGOW 2*nd October, and the* NORTH SCOTLAND SUB-CENTRE *at* ABERDEEN, 4*th October, and* DUNDEE, 17*th October*, 1957.)

This Address reviews some of the early contributions made by Scottish engineers to British industrial progress and discusses some aspects of present student education in Scotland.

About 250 years ago, at the time of the Union of Parliaments, Scotland was almost a feudal State with only a little shipbuilding, fishing and primitive coal-mining giving importance and employment to a few East Coast towns. About this time, however, the foundations of modern engineering were being laid in England by the development of the iron industry, and soon after, Dr. John Roebuck stepped on to the Scottish scene. Roebuck was trained in medicine at Edinburgh University, but subsequently, with the help of Samuel Garbett, a Birmingham business man, he entered the iron industry by building the Carron iron works, near Falkirk, in 1759. Whereas in England the iron industry had grown up gradually over a long period, in Scotland, due to Dr. Roebuck, it started suddenly and on a relatively large scale; the Carron works, which brought the word 'carronade' into the language, still prosper to this day.

Into this world was born the first of the great Scottish engineers, James Watt. In 1755, at the age of 19, he decided to become a mathematical instrument maker and, like many subsequent Scottish engineers, went to England for his apprenticeship. The journey took him twelve days over almost non-existent roads; returning to Glasgow as instrument maker to the University he interested himself in the steam engine. He devised the separate condenser, which, following Newcomen's idea of the separate boiler, so greatly increased the efficiency of the engine as to make it into the prime mover that introduced the industrial revolution into Britain.

It is important to realize that Watt did not suddenly come upon the idea of the separate condenser; he had wondered for a long time how to overcome the inefficiency of the Newcomen engine, and, setting an example to later students and engineers, he made a close study of the basic principles underlying the work he was attempting—he investigated the properties of steam. It was this fundamental knowledge that enabled him to visualize the solution to his problem when taking a Sunday afternoon walk across Glasgow Green. On Watt's death a monument was erected, by public subscription, in Westminster Abbey; in the Capital of Scotland a similar fund was inaugurated by Lord Cockburn which eventually resulted in a statue and in the Watt Institution and School of Arts; this Institution has developed into the Heriot-Watt College and the statue stands outside the present building.

William Symington of Leadhills also took out patents for a steam engine, leading to some discussion with Watt over possible infringements. One of Symington's engines was installed, in 1802, in the *Charlotte Dundas*, which sailed on the Forth and Clyde canal and was the world's first practical steamship. It is said that Robert Fulton, an American but the son of a Dumfries man, and Henry Bell of Linlithgow saw the trials of the *Charlotte Dundas* before developing the *Clermont* and the *Comet*, which achieved fame in their respective countries as pioneer steamships.

The deplorable state of the roads encountered by Watt on his journey to London was remedied largely by two men from Dumfries—John Loudon McAdam (1766–1836) and Thomas Telford (1757–1834). McAdam's major contribution was a new form of road surface comprising small stones laid to a thickness of about a foot on the natural soil, and so successful was his method that many miles were laid and he earned for himself the title 'Colossus of Roads'.

Telford in his young days worked as a stonemason in Edinburgh and subsequently built not only roads but also harbours, bridges, canals and tunnels and eventually became the first President of The Institution of Civil Engineers. Telford set an example to many later Scottish engineers by extending his activities outside Britain, a notable achievement being his construction of the Gota canal in Sweden. He also set another example that might well be followed by modern engineering students in that he was, on all occasions, well and correctly dressed.

Contemporary with Telford was John Rennie (1751–1821), an Edinburgh University student, subsequently employed by Watt. Among the numerous harbours and bridges that he built was the original Waterloo Bridge, which, although no longer in existence, is still regarded as one of the world's masterpieces.

Returning to mechanical engineers one finds the name of James Nasmyth, inventor of the steam hammer, who was born, educated and buried in Edinburgh. He started business as a millwright in Manchester in 1834 with one assistant, and, 22 years later, retired at the age of 48, leaving the large Bridgewater Foundry employing over 5000 people and was able to enjoy 34 years of retirement.

One must not forget the contribution of Scottish engineers to the development of the steam locomotive, and among many names, two stand out as having had influence far beyond the borders of Scotland. Patrick Stirling was born at Kilmarnock in 1840 and rose to be Locomotive Superintendent of the Glasgow and South Western Railway before going to the Great Northern in 1866, where he built the famous single-wheelers that hauled the East Coast expresses of the day at speeds up to 80 m.p.h. Engine No. 1, still preserved at York, took part in the great Railway Race of 1895, when the journey from King's Cross to Aberdeen was done in 8½ hours. The other name is that of Dugald Drummond, who became Locomotive Superintendent of the North British Railway, of the Caledonian Railway, and finally of the London and South Western Railway. Drummond engines were characterized by their simplicity and robustness, but, nevertheless, one of his engines, on the last night of the Railway Race, hauled the West Coast express over the difficult Caledonian section of the route from Carlisle to Perth at an average speed of 60 m.p.h.

It was while these spectacular achievements in mechanical and civil engineering were taking shape that Michael Faraday was laying the foundations of electrical engineering. The possibility of obtaining an appreciable and controllable force led several scientists of the time to devise simple electric motors. Robert Davidson of Aberdeen seems to be the only Scottish participant in the field at this time; by 1839 he had a lathe and a truck operated by electric motors; the Royal Scottish Society of Arts voted him a small sum for his experiments, which culminated in a 16ft battery-driven vehicle weighing 5 tons which ran at 4 m.p.h. on the Glasgow–Edinburgh Railway.

Little further electrical activity seems to have taken place in

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Scotland until the advent of William Thomson, Lord Kelvin. He entered the University of Glasgow at the age of 10 and carried off many prizes, finally proceeding to Peterhouse College, Cambridge. In addition to his academic distinctions, Thomson won the Colquhoun Sculls, founded the University Musical Society and spent some months in France, where he met many of the leading scientists; in these varied activities he set another example that present engineering students may follow with advantage. Thomson was thus well equipped to accept the Chair of Natural Philosophy at the University of Glasgow in 1846, where he remained until his retirement in 1899. Professor Dee has spoken of the 'Dilemma of Lord Kelvin'—should he devote his abilities to pure science or to its engineering applications? As his life progressed he tended more and more towards the second alternative, one result of which was that he died a rich man. Kelvin gave us the Atlantic telegraph cable, the heat pump, a host of measuring devices and, of course, Kelvin's law; he also invented, concurrently with Ferranti, the ribbon armature which was used in many Ferranti alternators.

Associated with Kelvin in his later years was George Forbes, appointed in 1873 to the Chair of Natural Philosophy at the Anderson College, Glasgow, now the Royal College of Science and Technology. Forbes definitely abandoned pure for applied science and set up as a consultant in electrical and civil engineering in London. With Lord Kelvin he was invited in 1890 to advise on the first hydro-electric scheme at Niagara and was appointed consultant to the construction company. It is not very widely known that, in 1884, he was the first to use the carbon brush.

In these early days two names stand out as the founders of the electrical manufacturing industry in Scotland—Henry Mavor and David Bruce Peebles. Henry Mavor entered upon a medical course at the University of Glasgow but abandoned that career in favour of an association with Col. R. E. Crompton in some of his early electric lighting schemes. Mavor then returned to Glasgow and set up arc lighting installations at the Post Office, Queen Street Station and elsewhere; the firm of Muir and Mavor was founded and the first public supply of electricity in Glasgow was given from Miller Street in 1885, so that by that time electrical engineering had become established in Scotland. Another notable achievement by Mavor was the first application of alternating current to ship propulsion in the 50-ton *Electric Arc*. David Bruce Peebles, who was born in Dundee in 1866, started a firm in Edinburgh to manufacture gas appliances; in 1898, seeing the rising importance of electrical power, he initiated an electrical department which has now grown into an electrical manufacturing firm known throughout the world for its heavy electrical plant. Although not born in Scotland, Jens La Cour, chief engineer of the firm from 1903 to 1907, contributed largely to its fortunes, and therefore to the fortunes of Scotland, by his invention and development of the motor-convertor.

The name of Munro has been associated with the Scottish electrical contracting industry since 1840, when David Munro founded, in Glasgow, the firm of Anderson and Munro. In the next generation John M. M. Munro was closely associated with the pioneer work of Crompton and Kelvin in various electrical installations, and in 1888 he built the first electric railway in Scotland from Carstairs House to Carstairs Junction, about 1¼ miles. In 1899 J. M. M. Munro was associated with Kelvin, Henry Mavor and others in founding the Scottish Centre of The Institution.

Scottish engineers have also been represented in the field of communication. Alexander Graham Bell, inventor of the telephone, was born in 1827 and educated in Edinburgh, although he subsequently moved to Canada and the United States, where the actual invention was made. Bell himself in his early years, his father and his grandfather were connected with the teaching of elocution and in vocal physiology, and, as with Watt, the development of the telephone was a spare-time occupation. Another Scottish name in the communication field is that of John Logie Baird, the first man to produce a practical television picture. Like Watt, who got his inspiration when walking over Glasgow Green, Baird is said to have formulated his ideas of television while walking along the cliffs at Hastings, where he had gone in search of sunshine. Baird achieved, perhaps, less than he deserved, as ill-health and lack of finance were often a handicap; nevertheless, starting with very primitive equipment he developed his mechanical scanning apparatus to such perfection as to be able to televise the Derby and other events in 1932. The world was then, however, entering the electronic age and another Scot, Campbell Swinton, as far back as 1908 had suggested that the cathode-ray tube might be applied to the problem. Although Baird's system was used for public transmission by the British Broadcasting Corporation, it could not compete with the alternative electronic system and its use was abandoned. Even after this setback Baird continued with experiments on colour television and other things until his health finally broke down in 1946 at the age of 58.

The last of the Scottish pioneers to be mentioned is Sir Edward McColl. He travelled the hard way—John Brown's shipyard, Glasgow tramways, Pinkston power station, the Clyde Valley Power Co., and finally, in 1927, Manager of the newly-formed Scottish Area of the Central Electricity Board. The McColl protective system became famous in both hemispheres, and long before the Second World War McColl had worked out plans for a pumped storage scheme at Loch Sloy. When the North of Scotland Hydro-Electric Board was formed in 1943, McColl was an obvious choice for the position of General Manager, and the economic success of the scheme, the greatly improved Highland amenities and the revival of local industries resulting from it are fitting memorials to one of Scotland's most famous engineers.

The names referred to are only a selection of those who, in the past, have made Scottish engineering known throughout the world—but what a heritage for so small a country and what a standard to maintain in the future. The students of to-day, and their teachers, have a great task before them if they are to maintain these high traditions.

The purely academic education available to undergraduates in Scotland has long been, and still is, at least equal to that obtainable elsewhere; particular attention is, however, now being paid to full-time and part-time post-graduate courses and to helping the student with such semi-technical matters as public speaking and acquiring an awareness of engineering achievements beyond the limited curricula of his lecture rooms.

Provision of a broad practical training has always been difficult in Scotland as no individual Scottish firm is sufficiently large to give, within its own organization, a training on as wide a scale as that provided by some of the large firms in England. A training scheme involving co-operation between a number of complementary firms seems, therefore, the only way in which Scotland can make her proper contribution to the practical training of British professional electrical engineers. Such a possibility was mentioned in my Chairman's Address to the South-East Scotland Sub-Centre in 1954 and was subsequently discussed by Sir Hector Hetherington of Glasgow University, Mr. William Fraser and Mr. J. S. Hastie in the West of Scotland, by Mr. W. B. Laing and Mr. C. M. Beckett in the East of Scotland, and also by a number of others, with the result that on the 12th January, 1956, Mr. Fraser convened, at the St. Enoch Hotel, Glasgow, a meeting of representatives of industrialists and academic bodies to discuss the matter. As a consequence a working committee was nominated to investigate the possi-

bilities and prepare a draft scheme for the vacation and post-graduate training of electrical engineering students by making use of the joint facilities of the Scottish electrical industry; a secondary objective was to interest senior school pupils in the possibilities of an engineering career.

After six months of intensive work under the chairmanship of Mr. Kenneth Atchley, the committee produced a scheme which was submitted to the nominating body and, with only small modifications, accepted by them on the 11th July, 1956. This date may therefore be regarded as the birthday of what is now known as the Scottish Electrical Training Scheme (S.E.T.S.), although, since one of the recommendations of the committee was that the scheme should be operated by a non-profit-making company, it was not finally incorporated as such until the 25th February, 1957.

The company comprises at present seven member firms (two heavy plant manufacturers, one switchgear manufacturer, one cable manufacturer, one light plant manufacturer and the two Scottish Electricity Boards; in addition a large electrical contracting firm is about to be admitted); it is managed by a board of seven governing directors representing the member firms and six advisory directors from the universities and leading technical colleges and one from the Scottish Council (Development and Industry). The first chairman of the board is Mr. Atchley.

Shortly after the birthday meeting an executive committee was appointed by the board and began work on the detailed organization. On the 1st January, 1957, a full-time and fully independent organizing secretary was appointed with appropriate staff and office accommodation, and recruitment of trainees commenced forthwith. That this was possible within one year of the original meeting at the St. Enoch Hotel was a notable achievement, and there is no doubt that many future Scottish engineers will owe a considerable debt of gratitude to Mr. Kenneth Atchley for the very great skill and enthusiasm with which he guided the working committee, and later the board, through the many legal, financial and academic difficulties encountered in putting the scheme on a sound basis.

This Scottish scheme offers a two-year graduate course as well as vacation and pre-college training; this summer 59 trainees have been enrolled, including seven graduates embarking on a two-year course, 37 vacation trainees and 15 pre-college trainees. It is intended that about 20 graduate trainees per year will normally leave the scheme as fully trained professional electrical engineers.

Each student spends periods of appropriate length in the organization of one of the member firms, the programme being arranged to give as wide an experience as practicable and a training in accordance with the recommendations of The Institution for practical training of professional engineers. Since Scottish engineering skill is renowned throughout the world, there is no doubt that trainees under the scheme will be in contact with the best modern engineering practice, and particular advantages are the very wide range of experience offered and the fact that this includes not only manufacturing experience but also, through the membership of the Electricity Boards and a contracting firm, experience in the utilization of the manufactured products. An important feature is that trainees are employees of S.E.T.S. and not of one of the member firms.

An obvious problem arising with a joint scheme of this nature is the maintenance of a corporate spirit among the trainees; this is achieved by periodic conferences of all trainees together with senior staff of the member firms, by the regular issue of a bulletin and by the fact that the scheme has premises in Glasgow which can be visited by the trainees and which act as a focal point for the organization. The first conference was held in September and the evidence from it indicates that S.E.T.S. has already become a major factor in the training of Scottish professional engineers.

With regard to the secondary objective investigated by the original working committee, it is proposed to organize short courses of 3 or 4 days each for selected schoolboys during their holidays; each course will comprise about four boys, and, since the activities of S.E.T.S. members cover the whole of Scotland, it is hoped that it will be possible to give opportunities to boys all over the country without an undue amount of travelling or staying away from home.

At present entry to S.E.T.S. is, for various practical reasons, limited to Scottish students or students intending to make a career in Scotland. It is my personal hope, however, that in the future the doors will be opened to students from England and Wales, from the Commonwealth and from foreign countries so that Scotland will be able to play her traditional part not only in training British engineers but in training engineers for service throughout the world.

It will require the combined efforts of Members, Graduates and Students of the Scottish Centre so to formulate the history of the future that a Chairman 100 years from now will be able to continue this great story of Scottish engineers.

The Institution of Electrical Engineers
Abstract No. 2498
Feb. 1958

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By A. J. COVENEY, Member.

'THE IMPORTANCE OF BALANCE TO THE ELECTRICAL ENGINEER'

(ABSTRACT *of Address delivered at* LEEDS, 1*st October*, 1957.)

Modern life continues to present complex problems, and the electrical engineer is becoming more than ever involved in them because of the increasing reliance of mankind upon electricity.

Already familiar with the principle of balance in physical matters and electrical circuits, he is therefore more amenable to the need for decisions to be based on a balanced view-point.

It is the application of this principle to the design, manufacture and installation of electrical switchgear which forms the theme of my Address.

Historical Review

> A false balance is abomination to the Lord:
> but a just weight is His delight.
>
> *Proverbs* xi. 1.

All the earliest known forms of measurement, for example the Greek *stade*, were essentially a means whereby it was possible to

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establish parity and fair dealings in apportioning rewards to individuals.

Horology provides us also with an early reference to balance. In the fourteenth century, Peter Lightfoot devised the first mechanical balance arm called a *foliot* for Wells Cathedral clock, and it was therefore the origin of the balance in modern watches and clocks. The Salisbury Cathedral clock mechanism, using a replica of the original *foliot*, is still in use. Other examples may be seen in the Science Museum, South Kensington.

Early Electrical Balances.—It is of interest to record some of the earliest forms of electrical balances. The Wheatstone bridge and the Kelvin balance are examples. Even to-day, at the National Physical Laboratory, a modern electrical balance is the instrument used to determine the standard unit of current.

The principle of balance is found in Kirchhoff's laws, which are an excellent basic example of its application to the solution of problems in electrical circuits. It was in the field of protective gear that the principle of balance was first applied to feeder protection. In 1904, Charles Merz and Bernard Price applied the principle to balance the currents at the ends of a feeder cable, and it was when this balance was disturbed that the faulty cable was isolated. Various modified forms of this early protection have since followed, resulting in the modern Solkor system, which uses only a plain 2-core pilot cable, and is immune, therefore, from the troubles of earlier designs, due to instability resulting from capacitance currents and frequency surges. Other types of protection, such as high-impedance pilot-wire protection and busbar-zone protection, also depend on the principle of balance.

Planning and Standardization.—The first essential of any enterprise, whatever its nature, is that it should have a balanced plan. Economics must always be a major consideration. An example of switchgear design made with this aspect as the main objective is the oil-immersed switch-fuse with 3-phase tripping, together with isolators, instead of the conventional type of circuit-breakers. Engineers must decide whether on balanced judgment the use of these units is justified, bearing in mind the loss of flexibility of switching occasioned by their use. The modern design is now capable of being closed on full short-circuit rating, and this has been achieved by the use of cartridge-type fuses and spring-assisted isolators.

In planning any new designs, there should be consultation between the user, who knows his own requirements, and the manufacturer, who knows how to meet these requirements most economically. The success of British designs in the past has been largely due to collaboration between user and maker. As a result there has been a tendency to standardize on one particular type of switchgear, with economic advantages, but we must be on guard that standardization does not preclude the use of switchgear embodying more advanced techniques. The balance between standardization and technical progress must therefore be continually maintained. An example of a design accepted as a standard over a long period is the compound-filled horizontal-draw-out switchgear of unit construction. Originally conceived over 50 years ago, the basic principles of construction and main dimensions have never been altered, with the consequent building-up of a valuable interchangeability feature. The balance has been preserved, however, by applying modern research and technique from time to time, so that the design conforms to the latest technical specifications. One of the original 1905 units, using brick frames, can be seen alongside a 1955 design in the South Kensington Museum.

Many examples of this class of switchgear can be seen in this area, extending over a period of 30 years.

The modern network analyser provides the electrical planner to day with a complete electrically-operated calculating machine, thereby enabling him to set up in miniature a complete system, and, by actual meter reading, to measure in advance the short-circuit currents, voltage drops, load flow and synchronous stability of the system under study. Flexible connections, at the same time, provide him with a quick means of making modifications to any system, thereby enabling him to balance his requirements and select in advance the most economical plan to pursue.

Research and Design.—Research engineers continue to try out new ideas and experiments, but there comes a time when a decision is necessary to balance between the need to continue with research and the necessity for marketing a finished product. Once this decision is made, the design engineer is only called upon for consultation if required, and is otherwise left to pursue his studies in research.

It must be remembered that the user always provides the final proof of any design, and whilst occasions in the past have been such that designers have made switchgear to certain express requirements of the user, and in some measure pioneered the way ahead, these instances, more often than not, have proved too costly and the designs have never been repeated. It is from such efforts, however, that experience is gained and a more balanced design is evolved. The first outdoor metalclad 66 kV unit installed at Bradford, and the first indoor metalclad 33 kV 1 500 MVA unit using gas-filled insulated chambers, are two examples. Another example of original design is the 132 kV 1 500 MVA metalclad unit installed for the C.E.B. at Tongland substation in 1932.

It was not until the late 'thirties that air-blast circuit-breakers were generally accepted in this country. Since then, development of these units has gone ahead from the original two blast heads to the modern design having four or more.

Experience has shown that the single base-insulators supporting the interrupter heads needed further mechanical strength, so we changed to tripod base-insulators. The increase in mechanical strength, however, resulted in the lowering of the electrical insulation level in service, so that the modern design, resulting from research and utilizing only two heads and a single base-insulator, represents a more balanced design from both the mechanical and electrical points of view.

The general tendency in design since the end of the war has been to reduce dimensions. This has been accomplished by more advanced techniques in insulation, for example the use of synthetic resin, and by developments in arc-control devices. The modern 11 kV 150 MVA 3-phase unit using vertical isolation has reduced the panel centres to 1 ft 10 in. The synthetic-insulated current and voltage transformers with a single-contact oil breaker contribute to the reduction in dimensions, but time will prove whether the balance has been disturbed by the reduction in the space factor. Many of the older designs are still giving excellent service and will continue to do so.

Manufacture.—Once a well-balanced organization is established, the importance is to produce a steady flow of products and to eliminate delays and stoppages. The methods of the production engineer and the amount of mechanization employed must be balanced with skilled and unskilled workers. Labour must be trained and employed efficiently and without discontent, and unless full co-operation with the worker is assured, the advantages in mechanization may be lost in labour disputes. If a balanced team from the works manager down to the last skilled operator is obtained, then there exists a human balance throughout the organization which promotes the good team-work so essential for success.

The contracts engineer is the link between the user and the works. His appreciation of works problems and his contact with clients must enable him to ensure that information and details are specified early to avoid delays in the contract, and he must at

all times ensure a balance between the users' requirements and standard products, and so assist in maintaining a balanced flow in the production lines.

Certification and Testing.—The electrical branch of engineering is probably more subjected to tests and certification of performance than is any other. This represents a considerable burden on the manufacturer and adds an appreciable amount to the cost of the product. Generally, the wider the range of products and the higher the voltages used, the more costly will be the testing equipment. The product must bear its share of the testing costs, and while there may be some unbalance in the early stages of a new design, as the turnover increases so the balance will be restored in relation to the proportion of the cost of testing to the price of the product.

Manufacturers' tests are primarily divided into: routine tests during the course of manufacture; heavy-current tests; light-current tests; high-voltage tests—both 50 c/s and impulse; long-duration tests; and, finally, high-power short-circuit tests.

Proving tests were initiated in this country at the British Short-circuit Testing Station, Hebburn, in 1929. It is largely from the data and experience gained during 30 years of this testing work that B.S. 116 was evolved and is still kept up to date as new developments arise.

The importance of all testing work is to prove whether a design is balanced in all respects; i.e. whether it is both mechanically and electrically capable of fulfilling the short-circuit rating ascribed to it by the A.S.T.A. certificate, and whether it will be able to maintain its performance through a wide range of current and voltage values.

Sales and Contracts.—As has already been stated, the contracts engineer fulfils a very important link in any organization, but to-day it is necessary to have specialized contracts engineers to cover the wide range of electrical products. While photography, colour printing, sound recording, portable film-projectors and other scientific aids assist the modern technical salesman, there is nothing that can be substituted for his personal contact and integrity. It is important that such men should continue to accept responsibility for the complete fulfilment of the contract and that there should be no break in the personnel. The experience gained from such wide knowledge enables him to keep a balance at all times between the interests of the buyer and the seller.

Commissioning and Site-Testing (Installation).—A man becomes an installation engineer only after years of realistic experience. Engaged with live apparatus, his responsibility is heavy. Safety precautions and routine must never be forsaken for short cuts to meet political or financial demands. I have witnessed breakdowns and injuries to personnel, due to moments of mental aberration, and so the problem of the human element is of prime importance. This element is a natural ability of self-control, which permits the engineer to be calm when faced with danger. He must always maintain an exact balance between what is definite and what is doubtful, and must possess the knowledge to make correct decisions. This natural ability is based upon a most acute awareness and is born from long experience.

Servicing and Maintenance.—The virtues of the servicing and maintenance engineers are not always fully appreciated. Some breakdowns in the past might have been prevented if their reports had been given earlier attention. It is, however, in times of emergency that one sees the service engineer at his best, and it is then that the co-operation between the maintenance personnel and the manufacturer's engineers is of great value. The formation under these times of stress of a balanced team of men, comprising the maintenance engineer on the one hand and the manufacturer's installation engineers on the other, contributes in no small measure to the rapid restoration of supply after breakdown.

Organization.—The rapid growth of some organizations over the last fifty years has resulted in some of them possessing vast economic and political influence. There is a danger, however, to their future success, due either to their having exceeded an optimum size or to the internal balance having been upset. When routine and paper supplant personal contact, when conflicting view-points and duplication occur, the economic balance is disturbed. Much has been written on the problems of management, but they will be more readily solved and satisfactorily dealt with if a balanced view-point is always maintained.

Training.—Never before has the demand for professional engineers and technicians so much outweighed the supply as it does to-day. The following birth-rate figures show that the number of males reaching the age of 18 has dropped considerably since 1938:

1938	442 000
1948	323 000
1957	303 000
1965	454 000

It will not be until 1965 that the numbers reach pre-war levels. Recruitment of technicians is therefore a problem of national importance, but it is still problematical whether, with the ever-increasing demands and scientific developments, a balance between supply and demand will be reached. While the authorities are doing all they can to encourage more entrants, the degree of specialized knowledge is increasing and reclassification in grades of scientific knowledge and technicians is essential.

The Institution has resisted any possible lowering of standards and has in fact raised them to meet the demands of specialized knowledge and responsibilities. It is important, therefore, that a correct and balanced intake of young engineers into the Specialized Sections and Groups be ensured. Entrants to-day should be trained to recognize that the future prosperity of the industry depends on their efforts, and they must balance the opportunities provided for them with a willingness to give at all times their best in labour.

Conclusion.—I have endeavoured to convey briefly the main aspects of the principle of balance and its application to switchgear and its associated problems. Engineers to-day are trained in scientific knowledge, guided by engineers of experience and wisdom, but if they are to be successful in meeting the demands made upon them, they must necessarily and constantly respect and apply at all times the principle of balance.

The Institution of Electrical Engineers
Abstract No. 2497
Jan. 1958
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EAST-ANGLIAN SUB-CENTRE: CHAIRMAN'S ADDRESS

By G. E. MIDDLETON, M.A., Member.

'EDUCATION FOR ENGINEERS'

(ABSTRACT *of Address delivered at* NORWICH, *7th October*, 1957.)

My justification for an address on this hackneyed subject is that as a teacher I enjoy confidences from pupils, parents and industrialists which are often very revealing. By engineers I mean Chartered Engineers, and of their importance in to-day's society there is no doubt, but perhaps because their standards are determined by reference to facts and not to opinions, these engineers are not always properly understood as persons in social life. The engineer's scientific methods give him confidence in his own capabilities, and this sometimes leads to arrogance but more often to an understanding humility.

Education I feel has three broad aims: to teach understanding of life as a whole; to foster genius; and to make a man useful. To achieve understanding is a very personal task, and many wise men have given us glimpses of greatness throughout the ages. I would only emphasize here that true education must provide ready access to books of all kinds, and, particularly for engineers from their earliest years, access to men of affairs. Engineering is a live activity, and its special ideas are better developed by active interchanges between people. Older engineers should go out of their way to reach intimate understanding with the younger, so passing on some of their philosophies at first hand to the developing generation. Education is for the improvement of individual capabilities, and the encouragement of genuine interests, not the imparting of set ideas through intermediaries.

To foster genius is vital for our country's future; my belief is that our finest national contribution to affairs is originality. We cannot, then, copy foreign methods, however streamlined and efficient they may be. When a teacher recognizes even a little genius in his pupil he should refrain from inflicting routine tasks and unnecessary exercises, and he should actively encourage his pupil's special bents. Academic discipline should be used only to guide zestful energy, not be made an excuse for quotas of written work.

An engineer, by definition, is a useful man. He thus has to learn words and techniques in a wide range so that he can deal with likely situations. His education must include a wealth of established material, but this should not overwhelm his teaching. Formal technical education is well provided for in this country, and we have enthusiastic teachers in all industrial areas. Most colleges I have come across have, however, proclaimed syllabuses which are far too ambitious for most pupils, and for them learning is too much of stark fact and bare routine. The pupils appear not to have time to do any critical thinking, nor are they encouraged to do any for examination purposes. Colleges could well review their work, trying less stereotyped questions in their papers, and teaching—even re-teaching—more examples of sound principles than of direct applications, especially in the courses for Higher National Certificates.

It is, however, at graduate level that so much more could be done by industry. Graduates are already trained for quicker appreciation of ideas than ordinary apprentices, yet so many are frustrated by slow and unimaginative time-tables. In a paper[1] presented to The Institution of Mechanical Engineers recently, the authors describe techniques which were so successfully applied to groups of undergraduates in factory courses that very useful and stimulating results were obtained. The enthusiasm generated was most striking. The same paper contains a searching analysis of the special attributes of graduates, and this should provide food for thought in those responsible for their training. Too many firms appear to waste bright men—and not only apprentices—in dull and discouraging tasks, and much could be done to relieve the shortage of technologists by encouraging and trusting the young men in responsibility.

One excellent way of developing a young engineer is by providing tutors in industry who can offer guidance and experience within the live environment of manufacture and research. Too many of our best students spend extra years at a university carrying out restricted research investigations which lack the life or urgency of the corresponding industrial problems. The university's function is to provide a three years' basis for future mental development, but more time than this is often devitalizing for the engineer. Where industry is prepared to be generous with tutorial time, the young graduates can tackle responsible problems and obtain useful answers in cases whose unusual nature makes them an embarrassment to the time of the regular staff of busy men. In Cambridge we have first-hand knowledge of many firms in which apprentices under guidance have conducted urgent technical investigations very successfully, and so have obtained a much deeper experience of practical realities than formalized training would give. Money spent on such tutorial effort is to my mind better spent than on increased stipends for teachers of young students who are without any knowledge of realities or of the complexity of real situations. An extension of this tutorial effort could be made to provide some new degree, or such distinction, for high-grade intellectual work carried out in the industrial context. This would offset the temptation now presented to young men to spend too long a period in the soft atmosphere of a teaching establishment purely to obtain a higher degree in the hope of impressing a prospective employer. Only a few men have the imagination which produces its results in academic isolation; most brilliant engineers have minds which are stimulated and developed best by fast-moving, vital and creative work in a good firm.

I have been reading a recent biography[2] of Brunel, the engineer. His father was able to give him the finest education available in the 1820's, and young Brunel was accordingly taken from school at the age of 14 to go to what might be termed a high school. By the time he was 16 he had completed his schooling and a good apprenticeship as well. He became engineer-in-charge of construction of the first Thames tunnel at the age of 20, and he was coping with a succession of crises of the sort which would daunt many a modern engineer. Where, in all the tidy and over-comprehensive schemes of to-day, could we discover and foster a man of such abilities? Let our teachers and tutors beware of losing the diamonds in the mass-flow curricula of our schools. Let us not forget that in giving too much instruction we stifle originality, elegance and fun, and all these factors are vital to man if he is to be worth while.

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The Institution of Electrical Engineers
Abstract No. 2499
Feb. 1958
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SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By O. I. BUTLER, D.Sc., A.M.I.Mech.E., Member.

'ELECTRICAL-STEEL LOSSES AT HIGH FLUX DENSITIES'

(ABSTRACT *of Address delivered at* SHEFFIELD, 16*th October*, 1957.)

Available Materials.—The two major advances in magnetic sheet materials, during the present century, were made in Britain; by Hadfield and his co-workers in 1903, when commercial silicon-iron was produced, and by Smith, Garnett and Randall in 1930, when grain-oriented (g.o.) iron alloys were evolved. In the latter case, the nickel-iron alloys were of primary interest, and it was left to the United States to develop, initially, satisfactory commercial silicon-iron alloys.

A cobalt-iron-vanadium alloy (49%, 49%, 2%) has become available within recent years, under the name of Permendur, with a saturation flux density about 15% higher than that of silicon-iron. However, its loss for medium to high flux densities at power frequencies is about twice that of silicon-iron. It has now been reported[1] that by extra special care in eliminating impurities and annealing in a magnetic field, a much improved material, named Supermendur, is obtained. It is claimed that at 400 c/s a Supermendur core provides approximately 30% more output than a g.o. silicon-iron core of the same size.

However, as the best compromise between performance and cost, silicon-iron remains the most widely used of all the available core materials. For distribution and power transformers, a considerable increase has occurred during post-war years in the use of g.o. silicon-iron; in Britain it is now being used for transformers up to 345 MVA. Also, despite initial pessimism, g.o. silicon-iron has been used for turbine-generator stators, the punchings being segmental to make the easy-magnetization axis of the iron coincide closely with the flux path in the core, where most of the iron loss and magnetic potential drop occur. It has been estimated[2] that, despite the use of higher flux densities, g.o. sheet can increase the efficiency of hydrogen-cooled generators by $\frac{1}{4}$%, and air-cooled generators by $\frac{3}{8}$%.

Lack of Iron Loss Data.—The choice of the most suitable material for use at high flux densities has been difficult, owing to the lack of reliable iron-loss data. In fact, during at least the past twenty years, maximum inductions have been used at power frequencies in the teeth of some industrial machines up to the saturation density of 21 kG, with little or no knowledge of the corresponding iron loss. A similar situation, if not more acute, has existed with certain machines for special applications where frequencies up to 2000 c/s are encountered and the demand for larger ratings from given overall dimensions is being intensified.

Available Data.—Cormack[3] has obtained iron-loss values at 50 c/s up to an induction of 20 kG for a specimen of high-silicon-content iron with a total-flux waveform very closely sinusoidal. Brailsford and Bradshaw[4] have recently obtained data at 50 c/s up to 24 kG for a variety of specimens with a high degree of distortion of the flux waveform, a correction being made to the estimated eddy-current loss to obtain an assessment of the hysteresis loss and the total loss with sinusoidal flux waveform. The authors[4] confirm that the hysteresis loss tends to attain a 'saturation' or maximum value at about the saturation induction when the frequency is 50 c/s.

Measurement Problems.—At present, iron-loss data at saturation densities and frequencies up to 2000 c/s are required to be determined for sinusoidal and other specific flux waveforms. The three main difficulties of such measurements are the production of high magnetizations, the control of the flux waveform, and accurate measurement of the loss.

A comprehensive survey of the merits of various forms of tester, including the Epstein and Lloyd–Fisher squares and the ring and toroidal forms, leads to the conclusion that the permeameter is the most suitable for flux densities up to and beyond the saturation value. Besides bridge and potentiometer methods, thermal and other types of wattmeter are available for power measurement. A compensated form of the thermocouple type of wattmeter appears to be the most suitable for all frequencies, whilst the electrostatic wattmeter is quite suitable for the higher ones. Alternatively, a novel thermal method[4] may be used, bearing in mind that errors of the order of 5% may be incurred.

With regard to the control of flux waveform at 50 c/s, I have found that a parallel-connected set of multiple-frequency generators, as used by Cormack, is extremely versatile in closely approximating sinusoidal, trapezoidal or other specific waveforms. Alternative arrangements using fairly simple feedback methods can be devised, which can more readily and accurately maintain specific flux waveforms at all frequencies.

Effect of Flux Waveform Distortion.—I have established that the total loss with a distorted mean-flux-density waveform, having a single and constant stationary value of B_{max}, is

$$W_{td} = W_h + \frac{K^2 p W_{es}}{1 \cdot 11^2}$$

where W_h is the constant hysteresis loss per cycle; K, the form factor of the e.m.f. induced by the distorted flux; and W_{es}, the eddy-current loss with sinusoidal flux conditions; p may be defined as the penetration factor of the iron, since it depends on the extent to which the distorted flux penetrates into the iron against the demagnetizing effect of the eddy currents.

When the flux penetration is virtually unimpeded by eddy currents, as in low-frequency magnetization with very little flux distortion, p is unity. On the other hand, with high-frequency magnetization it can be shown that

$$p = \frac{\Sigma n^{1 \cdot 5} B_n^2}{\Sigma n^2 B_n^2}$$

where n is any odd integer and B_n is the amplitude of the mean-flux-density harmonic of order n; i.e. p is less than unity.

It follows that the availability of a family of straight-line graphs of W_{td} to $K^2 p$, for a given frequency and a sequence of fixed values of B_{max}, allows the loss corresponding to any distorted flux waveform and value of B_{max} to be read off when $K^2 p$ has been calculated.

Further, work is proceeding to obtain a better understanding of the effect on the total iron loss of the presence of subsidiary maximum and minimum values of the mean flux density, which provide minor hysteresis loops superimposed on the major loop, as frequently encountered in rotating electrical machines. Results obtained so far indicate that the designer of electrical machines should, in the fairly near future, be able to predetermine the core and tooth losses with reasonable accuracy from reliable data at high flux densities, even when superimposed higher-frequency ripples are present in the distorted flux waveform.

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The Institution of Electrical Engineers
Abstract No. 2476
Feb. 1958

RUGBY SUB-CENTRE: CHAIRMAN'S ADDRESS

By W. J. CARFRAE, B.Sc.(Eng.), Member.

'TURBO-ALTERNATOR DEVELOPMENT, 1927–57'

(ABSTRACT *of Address delivered at* RUGBY, *9th October*, 1957.)

In 1927 the general size of unit lay in the range of 6–20 MW, the larger sizes, with a few exceptions, being 4-pole machines.

The Grid as we know it to-day was non-existent, and each municipality or power company had its own generating plant. There was therefore an extensive market for small units as well as large ones in the public utility field. Another feature at that time was the existence of non-standard frequencies and systems. A certain amount of 2-phase distribution was in operation, and comparatively large areas of 25 and 40 c/s supply were to be found up and down the country.

Turbo-alternators had massive stator frames of cast-iron construction, and the whole unit was carried on a heavy cast-iron base, making it appear very high above the floor level. The 'bread and butter' machines were 3 000 r.p.m. units of 5–7·5 MW capacity interspersed with 1 500 r.p.m. machines of 12–20 MW capacity.

About this period fabricated construction was beginning to enter the field, some of the earliest efforts being devoted to eliminating large stator frame castings, which with the growth of unit size were becoming an increasingly difficult proposition. An early effort involved the use of castings for frame sections fastened together with tie bars, but the use of cast-iron limited the application of welding. From section castings to steel plate was a short step, and the standard stator frame construction of rolled plates joined by tie bars and dovetail ribs was quickly reached. Non-magnetic retaining rings were first used on rotors about 1928 and soon became practically universal on all but the smallest machines.

The next landmark in turbo-alternator progress was the advent of the 33 kV machine: 33 kV transmission systems and 33 kV station busbars were becoming fairly general at that time, and the idea of connecting the generator direct to the transmission and eliminating step-up transformer losses was an attractive one.

The period from 1933 to the outbreak of war in 1939 was one of steady development in unit size. Some 75 MW units were installed about this time.

The war years were concerned chiefly with keeping plant running, and the installation of new plant was limited to that absolutely essential for defence purposes. A consequence of this restriction was the 'black' winter of 1947, when severe power cuts and shortage of fuel combined to make life extremely uncomfortable.

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Little can be said of operating experiences during the war years, but the recollection that remains uppermost is the pungent comments of operating men on the topic of barrage balloons. These were generally accounted to be a greater menace to electricity supply than any weapon produced by the enemy. A loose barrage balloon with several thousand feet of trailing steel cable could accumulate an extremely high static charge and eventually would be tolerably certain to foul a Grid line, with unfortunate results.

The next major development was that of the hydrogen-cooled alternator. Economic studies have shown that the increased efficiency of a hydrogen-cooled generator begins to offset the extra cost in the region of 60 MVA unit size at 50 c/s, and at 75 MVA a hydrogen-cooled machine becomes worth while.

The 60 c/s machine presents quite a different picture: its windage losses are a greater proportion of the total losses, and the increase in efficiency by changing over to hydrogen cooling is proportionately greater. Consequently, hydrogen cooling becomes economic at ratings of the order of 20–25 MW. The present American Preferred Standards go so far as to specify hydrogen cooling for ratings as low as 15 MW.

The frame of a hydrogen-cooled machine must be gas tight and provision must be made to prevent leakage along the shaft and the rotor lead passages. Two designs of oil-film seal are available for the first purpose, namely the floating ring seal with radial clearance from the journal, and the 'thrust collar' type of seal with axial contact on a shoulder turned on the shaft. The former is considered to be less liable to damage in the event of any irregularity in the seal-oil supply, although the hydrogen consumption may be fractionally higher than with the 'thrust collar' type. In practice, variations in gas consumption are more often attributable to minor leakages in pipework, valves, etc., than to design or condition of shaft seals.

It is worth remarking that the only running maintenance required on a modern turbo-alternator is on brushes and brush-gear, slip rings and commutators, and much thought has been devoted to the elimination of this work, with, however, only limited success to date. Schemes utilizing alternators and semi-conductor-type rectifiers for excitation purposes are in use, and these eliminate exciter commutators. Slip rings and brushes still remain. Until rectifying equipment capable of dealing with the excitation power required can be compressed sufficiently to be accommodated in the rotor shaft, the slip ring and brush problem will remain with us. Much research work is being

carried out on brush behaviour, etc., but the problem does not offer any easy solution.

Future developments of turbo-generators lie in the direct-cooled rotor and stator. Much work has already been done in this field, and a number of machines are in service employing this principle. The development of this type of winding, where the coolant is in direct contact with the conductor, is still proceeding vigorously, and machines of ratings considerably higher than anything under construction to-day may well be realized.

The Institution of Electrical Engineers
Abstract No. 2490
Feb. 1958

SOUTH-EAST SCOTLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By J. MENDELSON, Member.

'SOME RELATED ASPECTS OF TRANSPORT AND DESIGN'

(ABSTRACT *of Address delivered at* EDINBURGH, 15*th October*, 1957.)

Partly in order to propound certain reasonable generalizations the subject-matter has been restricted to industrial equipment. But nevertheless a wide range, in weight or size, is thereby covered in the full Address.

It is suggested that there is a tendency for technical developments to improve, not only service performance, but also transportability and even to facilitate miniaturization. As a ready illustration a histogram of a series of single-phase house-service electricity meters is shown in Fig. 1.

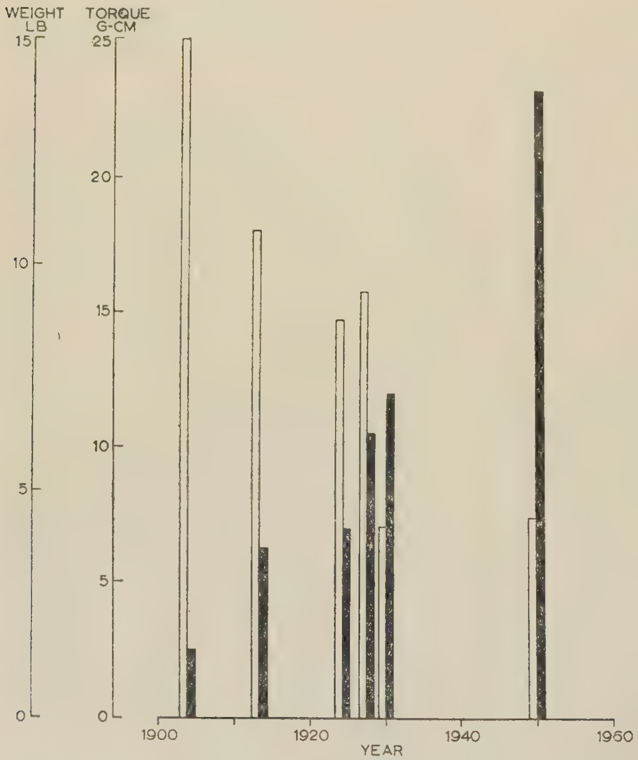

Fig. 1.—Total weights and driving torques of single-phase house-service meters.

Weight.
Torque.

One of the most vulnerable items in any deflecting or integrating movement is the pivoting. Detailed design problems for a wide range of driving torques and movement weights are therefore studied, and the practical solutions for four different examples are examined.

Amongst the beneficial and considered influences of modern techniques and materials, those due to the latest electromagnetic steels are particularly noteworthy. Thus in the histogram the great changes noted for the year 1950 are essentially due to the introduction of cast alloy-steel magnets. Similarly, in Fig. 2

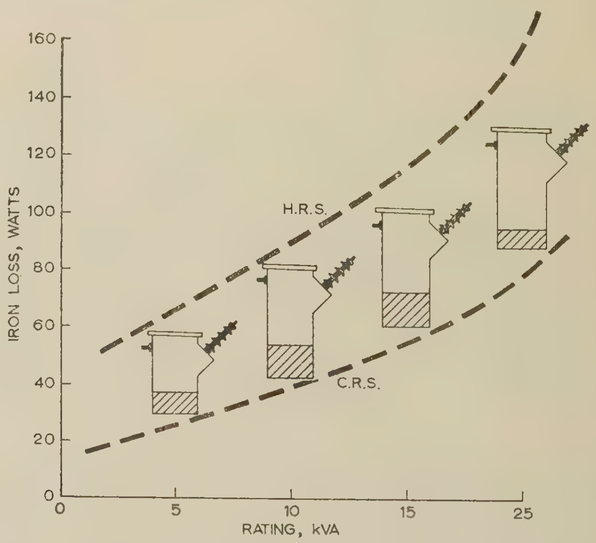

Fig. 2.—The advantages of cold-rolled grain-oriented silicon-steel.
C.R.S. Cold-rolled (wound core).
H.R.S. Hot-rolled
The cross-hatched areas represent the reduction in size effected by the change-over from hot-rolled to cold-rolled material.

Table 1

Type	Voltage	Rating	Core	Total weight
Indoor testing	1 phase 35 kV to earth	5 kVA 10 min 2 kVA 1 hour	Hot-rolled	150 lb
Rural	1 phase 11 kV	5 kVA 10 kVA 2 hours	Cold-rolled, wound	370 lb
B.E.A. T1	1 phase 11 kV	5 kVA	Hot-rolled	462 lb

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n attempt is made to show diagrammatically the major advan-ages gained in full use of cold-rolled grain-oriented steel for e cores of distribution transformers. Reductions in losses, mag-etizing currents and noise can be accompanied by dimensional eduction; thus progress has not been stifled by standardization.

No economic or marked other advantages can be reported in the use of aluminium for transformers.

To demonstrate the influence of short-time rating upon size, comparisons are made for one particular nominal rating of transformers. This is indicated in Table 1.

The Institution of Electrical Engineers
Abstract No. 2515
Feb. 1958

SOUTH-WEST SCOTLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By A. J. SMALL, B.Sc., Ph.D., Member.

'THE DEVELOPMENT OF AN ELECTRICAL MACHINES TEACHING LABORATORY'

(ABSTRACT *of Address delivered at* GLASGOW, 15*th October*, 1957.)

In 1955 Dr. E. Wilkinson, in his Chairman's Address to the cottish Centre, stated that the advancement of knowledge hould include, not only technical research, but also research nto the development of methods and apparatus used in teaching. teaching laboratory is primarily intended to demonstrate rinciples, to give variety in methods of measurement, to test nitiative and, above all, to encourage the student to think for imself. The development of apparatus for such a laboratory governed by such considerations as the simplification of exist-ng methods of teaching, improving their instructional value, ncreasing their accuracy and the ease of measurement.

A university electrical engineering laboratory, in addition to aintaining electrical standards and providing facilities for esearch in all branches of the science, must provide laboratory aining for undergraduates taking degree courses in electric rcuit theory, electronic engineering and electrical machinery. o deal with all these sections in a short address would be npossible; attention was therefore confined to a discussion of e equipment of a new Electrical Machines Laboratory in the niversity of Glasgow.

Essential Elements of an Electrical Machines Laboratory.—An ectrical machines laboratory comprises four essential elements: ources of d.c. and a.c. supply; the machines themselves; easuring instruments for current, voltage, power and speed; nd loading devices, such as brakes and resistors. Details of ese were referred to and illustrated with lantern slides in the ourse of the Address. Although many of the items are, in fact, esigned on conventional lines, the modifications which have been ade are of sufficient interest to merit some attention.

There are distinct advantages in possessing, in addition to new achines and equipment, some venerable pieces manufactured in e days before machines were more or less totally enclosed. uch old machines are unsurpassed for purposes of demonstration for standing extreme overloads. Nevertheless, the appearance a modern electrical engineering laboratory differs considerably om that of, say, ten or twenty years ago. At that time, rows machines on concrete bases and rows of marble or slate panels mote from the machines which they controlled were the usual ature. These are now obsolete, and have been superseded by uipment constructed on a unit principle.

Machine Unit.—In this, the machine is supported on a steel ame which also carries the necessary switches, starter and sistors; there is also a panel on anti-vibration mountings with the instruments, terminals and links requisite for the connecting up and testing of the machine.

This 'unit' arrangement has various advantages: the instruments, being permanently associated with the machine, are immediately available, so that time is not wasted in finding portable instruments; the terminals on the panel enable the various parts of the circuit to be interconnected conveniently; and the machine and all its auxiliary apparatus can be moved easily from one site to another.

The importance of students doing the connecting-up of the apparatus is fully appreciated and its educational value has not been disregarded. For the training of junior students all the elements of the circuit are brought to the terminal board and must be connected by them, but on machines tested by advanced students, ammeters, voltmeters, resistors, etc., are usually permanently connected, their position being shown on the panel diagram. The advanced student is thus free to devote his time and attention to developing experimental facility and procedure.

Examples of both junior and advanced machine units which were given in the Address illustrated the method of overcoming the difficulty of adjusting a mechanical brake to give steady conditions, namely by the use of an oil dashpot inserted between the spring balance and its attachment to a brake-band having friction pads (based on a design used at Cambridge University); an accurate, speedy and convenient disc-type stroboscope, as an alternative to a stroboflashing device, for the measurement of the wide range of slip of an induction motor tested from no-load to stalling-load; and a layout for the investigation of the transient and frequency responses of a completely automatic Metadyne-controlled mechanism.

Demonstration Apparatus.—Demonstrations before large classes can be effectively assisted by an assembly of 15 in scaled instruments or indicators on an angle-iron frame suitably mounted on castors to facilitate movement from one lecture room to another. Shunts and multipliers can be located remote from the indicating panel but connected to it by a multi-core screened cable.

Teaching apparatus includes demonstration apparatus as well as experimental apparatus. Whereas with experimental apparatus the student learns by doing and recording results, the object of demonstration apparatus is to supply a visual aid to the understanding of a principle or a theory.

Details and illustrations were given of apparatus for demonstrating Ward Leonard control and for synthesizing the symmetrical components of unbalanced 3-phase systems.

Supplies and Interconnections.—The preparations for the

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removal of the Electrical Engineering Department at Glasgow University from the James Watt Engineering Laboratories to a new building on an adjacent site has necessitated many decisions being taken, one of the most important being that concerning supplies and interconnections.

The supplies available throughout the machines laboratory are

(*a*) Four-wire 415-volt 50 c/s alternating current stabilized to 1%.
(*b*) Three-wire 500-volt direct current from mercury-arc rectifiers.
(*c*) Low-voltage batteries.

A large 250-volt battery, with its costs of maintenance and replacement, is now regarded as unnecessary. The problem of the excitation of certain machines, such as alternators, can be overcome by the provision of individual metal rectifiers.

Ducts embedded completely in the concrete floor of the laboratory and provided with ample and conveniently placed access points are the most satisfactory means of interconnection, particularly as regards flexibility and appearance. For a given layout of the machines only some of the access points will be required, and two or more machines can be arranged round each of them, a suitable distribution pillar or control unit being provided.

Conclusion.—The examples chosen served to illustrate a few of the methods which have been developed to improve the availability of the apparatus for its particular purpose and to encourage students to consider why a given technique is especially suitable for a particular measurement.

If the apparatus has a good appearance the student will be encouraged to respect it and therefore to take more care in using it. If, in addition, he sees that an effort has been made to ensure satisfactory operation and to facilitate his use of it—and this can be done without spoon-feeding—he will respond and his interest will be maintained. The developments described have gone some way toward maintaining this interest.

The Institution of Electrical Engineers
Abstract No. 2481
Feb. 1958

NORTH-WESTERN MEASUREMENT AND CONTROL GROUP: CHAIRMAN'S ADDRESS

By E. ROSCOE, J.P., Member.

'SPECIALIZATION IN EDUCATION AND INDUSTRY'

(ABSTRACT *of Address delivered at* MANCHESTER, 22*nd October*, 1957.)

It appears to be appropriate for a Chairman of a Specialized Group to consider briefly the problem of specialization as it affects education, industry, and institutions such as ours. The problem of specialization has affected not only the electrical engineering industry, but many phases of society, e.g. the distributive trades in large centres of population, where each shop now specializes in a particular line. The hospital of the days of Florence Nightingale is rapidly disappearing. Special hospitals are built to deal with a specific disease. Doctors specialize more and more, and the general practitioner is rapidly becoming a diagnostician who treats only minor ailments.

Growth of Knowledge.—The designation 'electrical', 'mechanical' or 'civil engineer' is a fairly recent division, which only broadly describes the sphere of his professional knowledge and skill. The depth and breadth of knowledge expands at such a pace that it is difficult to keep abreast of it even in a very limited field. This can be seen by the number of technical publications in all languages. It is a problem to find time to read enough of them to feel fully informed in one's own field.

Within their lifetime men like Colonel Crompton and Dr. Ferranti saw the electricity industry develop from the very beginning into the highly specialized industry of to-day. It is remarkable that a biography of Madame Curie and the book on Calder Hall should have been published within the short space of 20 years. He would be a brave man who attempted to forecast the effects of recent scientific discovery on society during the next generation, especially now that man-made satellites are circulating round us. If the growth of knowledge continues at its present rate, more and more specialization appears to be inevitable in industry, education and engineering institutions.

Education.—A balanced educational system has a twofold purpose: to teach the theory and practice of earning a living; and to teach individuals about the business of living in a society.

Because of the scope of modern knowledge, specialization will, and must, occur at some stage of schooling. I sometimes wonder whether professional institutions as a body take enough interest in education at the primary and secondary levels. It is on this that a university education is built. At 11+ the child is channelled, in the majority of cases, into one of three types of school, which largely determines his future career. He must go to a modern, a technical or a grammar school. At 15 years of age the path diverges again to industry or to further educational specialization. Again, at 18 or 19, when the student goes to the university, he selects one or two fields of study. At the age of 22 or 23 he may enter industry and find himself once more facing the problem of deciding in which branch to specialize. I am convinced that the channelling of children at the stage of the 11+ examination is much too early in life. A period, from the age of 12 to 18 years, could be more usefully employed in a broader training than is given in any type of secondary school to-day and in guiding young people in their choice of a career. Special study should commence after the age of 18, continuing for at least three or four years at a university. A post-graduate course in social studies should be added to a degree or Higher National Certificate, if we are to aim at a well-balanced educational system. This might relieve some of the present tension in society. I believe that every engineer could benefit from a knowledge of the history of his profession and the lives of those who pioneered it.

Industry.—Since specialists must work together in teams in industry and at the university, and pool and co-ordinate their knowledge, residential courses covering a few months might be held in further educational centres, where problems in human relationships as well as technical problems can be dealt with. Part of the manager's duties is that of functioning specialist, especially where the work consists of scientific research and development, and to a lesser degree, the application of science to industry.

There is a danger that, if engineers do not give some thought to these and other related problems, the administrative side of the electrical engineering industry may pass into the hands of people who have not an engineering background and the engineer become merely a specialist in some branch of his profession.

Mr. Roscoe is with the North Western Electricity Board.

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The Institution of Electrical Engineers
Report No. 2551
Feb. 1958

DISCUSSION ON 'THE SUPPLY AND TRAINING OF TEACHERS FOR TECHNICAL COLLEGES'

The Willis Jackson Report

The Report of a Special Committee appointed by the Minister of Education was discussed at an Ordinary Meeting of* The Institution, *7th November,* 1957. *It was introduced by* Dr. Willis Jackson, *Vice-President* (*Chairman of the Committee*). *The account of the discussion is preceded by the constitution of the Committee and a summary of the Report.*

THE COMMITTEE

(*a*) Willis Jackson, D.Sc., D.Phil., Dr.Sc.Tech., M.I.Mech.E., Vice-President I.E.E., F.R.S. *Chairman.*
(*a*) (*b*) R. McKinnon Wood, O.B.E., M.A., F.R.Ae.S. *Vice-Chairman.*
(*a*) Frank Briers, B.Sc., D.Phil., F.R.I.C.
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SUMMARY OF THE REPORT

The Committee was constituted in the autumn of 1956 with the following terms of reference:

To consider in the light of the White Paper on Technical Education (published in February, 1956) the supply and training of full-time and part-time teachers for technical colleges, and to make recommendations.

The main objectives of the White Paper may be summarized as:

(*a*) An increase in the annual output of students from advanced courses, visualized mainly as full-time and sandwich courses, from the 1955–56 figure of 9 500 to 15 000.
(*b*) An increase in the number of students attending part-time day courses during working hours from the 1955–56 figure of 355 000 to 700 000.

This programme of expansion is to be associated with a building plan for the technical colleges of which the last projects are to be commenced by 1960–61, and of which the cost, inclusive of laboratory equipment, is expected to be of the order of £100 million.

Expressed in terms of teaching work—student-hours—this represents an increase of roughly 50% over that of the 1955–56 session.

The Committee ascertained that in the latter session the colleges had about 11 000 full-time teachers, not including the principals and vice-principals, and some 40 000 part-time teachers. The number of full-time teachers had increased at an average rate of 770 per annum, and that of part-time teachers at about 2 000 per annum, during the preceding three years. But although these had been encouraging rates of growth, they had not been adequate to deal effectively with the increase in student numbers, and a mere continuance of them would fall far short of satisfying the requirements of the situation anticipated in 1960–61.

The estimates of need up to this date to which the Committee were led amount to 7 000 additional full-time teachers of all grades, and 8 000 additional part-time teachers, above the 1955–56 figures. The percentage increase in the number of full-time teachers—some 64%—is much greater than that of part-time teachers—20%—in consequence of the changing character of the colleges' work in the direction of more full-time and sandwich-course work, and of an extension of part-time day as against evening study, both of which—in the opinions of the colleges and the committee—can be handled most effectively by full-time staff, if this can be made available. Converted into annual figures, this means that the number of full-time teachers *in service* will need to increase over the five years in question at the rate of 1 400 per year, as compared with the recent annual rate of 770. A maintenance of the 1955–56 ratio between the contributions of full-time and part-time staff, on the other hand, would reduce the need for additional serving full-time teachers to 5 500 and the annual rate of increase required to 1 100.

The question which follows from these data is: What do they mean in terms of actual *recruitment* when account is taken of the likely rates of death and retirement, and of wastage from the colleges to other kinds of employment? The evidence available suggested an annual loss rate of 6% of the number of serving teachers, which, when applied to the increasing teacher strength envisaged, means an average annual recruitment of full-time teachers over the 5-year period of 2 300 or 1 800 on the two criteria stated above. These figures are to be compared with a recruitment rate of 1 300 during recent years.

It was evident to the Committee that greatest difficulty was likely to be experienced in obtaining an adequate recruitment of well-qualified teachers of science and technology for professional courses at the intermediate and advanced levels. It therefore made a special study of this problem, and deduced that the recruitment of mathematics and science graduates will need to rise from the recent annual rate of 300 to a figure of 400 per year and of technology graduates from 150 to 360. Moreover, although outside the purview of the report, note must be taken of the considerable university expansion now in progress which seems likely to call for the recruitment of some 200 graduate scientists and 150 graduate technologists per annum during the next few years.

Although the recent technical-college recruitment figure for mathematics and science graduates of 300 per year has been a gratifying achievement from the point of view of the colleges themselves, the fact that it has occurred mainly through transfers from the schools gives cause for serious anxiety. So far as technology graduates are concerned, the increased number required can come only from industry and appropriate Government Departments, since practical training and experience are essential for teachers of technology.

It is evident that, for some time to come, industry must be

* H.M. Stationery Office, 1957 (4s.).

willing to accept, and indeed to encourage and assist, the transfer to full-time teaching work of experienced staff members it can ill afford to lose, as the only means of ensuring a much augmented future supply of junior recruits of high quality.

The Committee made no recommendations on salary scales, since with the recent changes made by the Burnham Committee, it is open to local authorities—by using to the full their discretion in the grading of posts and in the awarding of increments on first appointment for previous experience—to pay salaries to full-time teachers which compare more favourably than is generally supposed with those available in industry. But it found that transfer from industrial employment to full-time teaching work is often hampered by pension considerations, and the Committee hoped that arrangements might be made for a paid-up policy to be granted to those who resign to take up teaching, so that a pension would be due to them on their eventual retirement.

A considerable section of the report is devoted to a number of matters concerning the conditions of service in technical colleges on which the Committee feel that effective action by the education authorities and the colleges themselves is required if service in technical education is to be made adequately attractive to men of high qualification and ability. These matters include: the avoidance of excessive teaching loads; the more generous provision of clerical, workshop and laboratory assistants; improved opportunities for conducting research work, desirably in close collaboration with local industry, for periodic return to industry for further experience and for the carrying out of remunerative consultative work.

The contribution of part-time teachers, particularly those in industrial, commercial and Government employment, will continue to be of great importance in helping to maintain an essential close contact between the colleges and the outside world, and to ensure that the teaching takes proper account of day-to-day industrial and commercial experience and of the latest developments. With the rapid growth of day courses, their help during the day-time, and not merely during the evening, will become increasingly necessary.

The extent of this need will be affected, of course, by the ability of the colleges to recruit full-time staff, but the need will in any event be large, and the report emphasizes that, unless employers are prepared to arrange on a greatly increased scale for suitable members of their staffs to teach part-time during the day, the colleges may find themselves unable to make the educational provisions required. As a particular aspect of this help, the Committee has recommended that carefully selected senior staff members of industry, commerce and Government Departments should be brought into close and responsible association with the academic activities of the colleges of advanced technology and the regional colleges through part-time appointments carrying a special status and title, as is common practice on the Continent and in Russia. It visualizes that they would help, not only with the advanced teaching work, but also with the formulation of academic policy; that they might carry a title such as Special or Associate Lecturer or Reader and receive an appropriate honorarium.

The report emphasizes the importance of a high quality of teaching, and discusses the desirability and practicability of a large-scale expansion of the facilities for technical-teacher training. While recognizing that not all technical teachers need, or would be willing, to undergo training, and that it would not be practicable in any case to insist on this under present circumstances, the Committee feels that a greater number, particularly of those to be engaged in teaching at the less advanced levels, should be encouraged, and be afforded more generous financial incentives, to undertake it.

The position in session 1955–56 was that, of the 11 000 full-time technical teachers, about one-third had received teacher training, but of these the great majority were teachers of subjects other than technology who had been trained for service in schools, either in the university departments of education or the teacher training colleges.

The facilities available for technical-teacher training specifically comprise colleges in Bolton and Huddersfield and the Garnett College in London, which together accommodate about 300 students. An extension of these facilities, involving new buildings and residential accommodation to a capacity of 500, is recommended, this figure to be reviewed in two years' time, when it is likely that a fourth college should then be established in the Midlands.

The present course is pre-service and of a year's duration, and it is suggested that, in supplementation of this, there should be introduced for teachers already in service a 3-term course, conceived as a whole but capable of being taken one term at a time at intervals of a year or more. It is recommended that on secondment for participation in the latter course, teachers should continue to receive full salary plus an allowance towards the additional cost of maintenance. The improved grants recommended for pre-service training are designed to reduce the disparity in financial circumstances which would otherwise exist between those who wish to train before beginning to teach and those who go direct into teaching posts and take in-service training at a later date.

An associated proposal to the Minister is that a residential staff college should be established in which senior staff members of the colleges and representatives of industry, commerce, Government Departments and the universities and schools could live together for periods of a few weeks to discuss the aims, needs and methods of technical education in the light of experience and developments in these related fields.

In view of the urgency attaching to publication of the report, the Committee was unable to give as much attention as it wished to many matters falling within its terms of reference, and it therefore recommends the setting up of a permanent advisory committee so that these matters can be pursued and the whole subject of technical teachers kept under continuous review. The task disclosed by the inquiry is a difficult one, but one which must be accomplished. Its accomplishment will require the forging of a much closer partnership between the technical colleges and industry than has yet been achieved, and in the opinion of the Committee: 'There must come to be a much greater interchange of staff and ideas between them, and it must become a commonplace for individuals to move from one domain to the other, and back again, or for them to be fully recognized members of both at one and the same time. For some years, industry must be prepared to lose more than it may appear to gain'.

DISCUSSION BEFORE THE INSTITUTION

The Rt. Hon. Geoffrey Lloyd, M.P., Minister of Education: I am very pleased indeed to have the opportunity of being here this evening and of hearing Dr. Willis Jackson deal with some of the aspects of his invaluable report. It is a survey of our needs in respect of the training and quality of the technical personnel which, I am sorry to say, I understand has never been done before in this country.

It happens that I am the first Minister of Education to receive a scientific education. You will not be surprised, therefore, if I tell you that my approach to this general subject is that our

ountry has, for several generations, scandalously neglected its echnological education. I do not mean in terms of quality, ecause we have had a very high quality; but we have not had ufficient quantity. I feel that we have to make a drastic change n our approach as a nation to this great problem. Particularly o we need to do that because of the great pace at which science s progressing in very many different fields, and what I call the ertilization of ideas', the interaction of one field of technological dvance upon others which gives rise to a very great pace in the eneral advance of our scientific, industrial and technological ivilization to-day.

I should like to make one other general point. I think we ave also neglected scientific education—again as regards uantity. You will agree that when you are trying to discuss a echnical or a scientific problem with people who have had no cientific training at all, they have the greatest difficulty in understanding what you are talking about. In this age when the rogress of great countries depends so much on the progress of cience and technology, that is a great weakness. Therefore, think that the spread of scientific education in our schools is very good thing.

Another point about which I feel strongly is that we do need nore technologically and scientifically educated people at the ead of the boards of directors of the firms in this country. fter various movements in the last two or three decades, in ecent times there has been a movement whereby qualified ccountants have become a very important influence. I am not aying anything against that; but I do say that it is more important n the future that technology and science should be represented t the top in the directing bodies of industrial concerns.

I would refer once again to the Willis Jackson Report and say his. It deals with the proposed great effort to make a big ncrease in our technological education, and reference is made to he £100 million programme. The facilities are all very important, f course, to enable the teachers to function properly, but the upply of teachers is in the last resort the most important factor, nd it is when you come to the teachers that you strike the uestion of quality. Therefore, while we are increasing the uantity we should not sacrifice the quality but, if possible, hould increase that as well.

Dr. Willis Jackson asked me whether I could reassure him on he question of Government expenditure on technological ducation, and I am very glad to say that I can do so. From he announcements recently made by the Chancellor it is clear hat there will be no reduction in expenditure on the programme or technological education.

I should like at this stage to say how very pleased I am—and am sure we all are—to have with us this evening a representative rom the United States, Mr. Maynard Boring, a member of resident Eisenhower's Committee on Engineering Manpower. We are delighted to see him here, a distinguished consultant ngineer, in a representative position taking part in our discussion o soon after the Prime Minister and President Eisenhower made heir declaration of common purpose in Washington.

Here I should like to say something which I believe applies to oth our countries and is relevant to what we are discussing this vening. It is in relation to the Russian satellites. I was very lad, as I am sure we all were, that the President of the Royal ociety sent congratulations to the President of the Soviet cademy of Sciences on this great scientific achievement. It is nteresting to consider how many different kinds of technology vere involved in the launching of the satellite: metallurgy, allistics, aerodynamics, electronics, chemical engineering—it dds up to a fairly formidable list, and of course expenditure ust have been vast. I might say it is interesting to me as a Minister to reflect that it would not be constitutionally possible for the British Government to surprise the world by launching a satellite, because with such vast expenditure on a project of that nature there is no doubt that estimates would have had to be laid before Parliament at an early stage, and the whole project would have had to run the gauntlet of public scrutiny and criticism. I mention this because it is important to bear in mind when we are told that this is what a dynamic communism has and we have to have the same. It is a fact that in Russia the Kremlin decides, whereas here, and in the United States, there is a partnership between Government, Parliament and public opinion, and I think in the Willis Jackson Report it is shown that this has to be a partnership between local education authorities, the Ministry, the teachers, and so on.

Therefore it is a particular pleasure to me to-day to see this great technological industry having a meeting and being appealed to by Dr. Willis Jackson to play its own particular part in co-operating in this big undertaking. Having studied the report and also the very interesting report of the engineers' mission which went to study technological education in Russia, I feel it is clear that the co-operation of the large firms—which to a large extent we have already—and the small firms is vital to the success of the new colleges of advanced technology and diplomas of technology. I am very glad that it is beginning and I think it important that it should be continued. We shall not get the highest quality of teacher unless it is possible for a certain degree of transfer to take place between technical colleges and industry, because on the one hand the technical colleges need to be up to date and know the latest methods of teaching, and on the other it will be vital to see that from the financial point of view there is no sacrifice on the part of the teachers, but rather, perhaps, financial advantage.

It is at this point that I should like to refer to one of Dr. Willis Jackson's recommendations. It is the idea that teachers at the technical colleges should be of such a standard and should have the freedom to do a certain amount of consultant work for outside firms and be allowed to keep the fees, because I think that is very important to the way in which we may be able to loosen up the relationship between industry and the technical colleges.

Thank you very much for listening to me. I have come here in pursuance of the second phase of the work following the Willis Jackson Report. We have studied the report and we want to hear from the principal interests concerned, and you are one of the principal interests. We shall then hope that we shall quickly make our decisions.

Mr. E. G. Godfrey: The report is the first comprehensive study which has been made of the problem of the supply and training of technical teachers. The training of teachers for schools has been the object of study and action for many decades, and since 1945 every entrant to the schools has required to have had at least two years' full-time training. This will be shortly increased to three years. To enter as a teacher into technical education there is no formal requirement for qualifications of any kind. In practice the number of qualified people is rising rapidly, and the report will be of great assistance in the future. To ensure that the problem receives continued study a standing advisory committee must be set up.

The first requirement of a teacher in a technical college is that he should be—a teacher; preferably one who has been trained to use the wisdom of educational experience and who by appropriate study has mastered the knowledge of his subject. He will be the better teacher if he can illuminate his work as a result of up-to-date experience with industry and inspire it as a result of contact with research. The report will be useful in securing that teachers at all levels, to the appropriate degree, are helped to meet such requirements.

In spite of the absence of formal requirements on qualifications, the report shows that 59% of the staff have degrees or degree equivalents and about 33% have been trained as teachers. While the report admits that this is a highly qualified body of people, it takes a somewhat static view of their capacities. I am confident that there are large numbers who will show themselves capable of developing to high levels of work if they are given the conditions proposed in the report. Surely it is necessary to make the fullest use of the resources we already possess.

The problems of supply have become more difficult in the last year. Not only is it difficult to get staff at the lower grades, but it has become almost impossible to attract people from industry at the senior lecturer level, especially in electrical engineering. This is partly a matter of salary—certainly at the lower levels—but undoubtedly the conditions of work have their effect. Reductions in the present excessive teaching hours, opportunity for research, provision of clerical and laboratory help, secondment to industry, facilities to attend conferences and the like—all will help to make the profession more attractive.

The report stresses that the present average teaching hours are excessive, yet its target figures for recruitment are based on existing hours and at the same time it recommends the development of research, secondment to industry and release for training, etc. These proposals will all increase the teaching hours of the remaining staff unless college establishments are increased to take account of the hours so spent. We welcome all these proposals, but suggest an additional recommendation that college teaching staff establishments should be sufficient to cover both teaching and all these other activities.

The real question we are facing is the practical one of the implementation of the report. Here the basic problem arises from the fact that out of 46 recommendations, 32 involve greatly increased expenditure on staffing by local education authorities already committed to rising expenditure on buildings and students. If we accept the proposals of the report as necessary to the development of technical education, we must study its financial implications in connection with the new Local Government Bill, with its proposal for the finance of education by a general grant instead of the present percentage grant system.

Mr. L. J. Davies: I speak as an industrialist to give full support to active co-operation between industry and technical colleges, developing, in a form to suit local conditions, into a partnership devoted to the education and training of technicians and technologists. I speak with experience of Rugby, where the environment is helpful, since Rugby Technical College deals, on the advanced side, with the technologies of one industry only and has to meet the needs of but two companies. This situation favours the setting up of compact committees and working parties formed from the College staff and industrial specialists. A great deal of work has been and is being done by these groups. Almost every conclusion reached supports the recommendations of the report. It may be of interest to outline the present position.

First on the transfer of men from industry to full-time teaching: this is a change of career. Where men have made this change from local firms to the College, I understand that their teaching has been effective and the change successful. However, except in special cases this particular move should arise first in the mind of the man concerned.

The release for part-time teaching falls under two headings: that of senior engineers and specialists to give courses of lectures on their own particular subjects arises whether there is a general shortage of teachers or not. At Rugby the plan evolving is that selected individuals will be released for one half-day per week for a course normally consisting of one lecture a week for six to ten weeks per session (in a sandwich course there are two sessions per year). No salary deduction is proposed and an honorarium payable by the College is agreed in principle (40 guineas per session has been suggested). The College will confer the title of 'Associate Lecturer' and will invite such lecturers to join a board of studies. They will thus influence, to an extent dependent upon the individual, the general academic affairs of the College. Courses will be on such matters as computing methods and the solution of engineering problems, closed-loop servo systems, high-voltage phenomena and their application to switchgear, semi-conductor devices, automatic control systems.

Among the schemes being considered for part-time release to help to make up the shortage of teachers for routine syllabus subjects is one to invite young men just emerging from their graduate-stage or sandwich-course training periods, to teach for one half-day or one day a week, normally for one year. It is thought that when a man has only just joined his department he will be more easily spared and will find it easier to develop enthusiasm for certain outside duties than when he has got into the swing of his departmental duties. There would be no deduction of emoluments by industry, but the company concerned would be reimbursed by the local education authority at an average flat rate per hour, the man being paid the difference between this and the particular teaching rate of the authority. The man would thus suffer no sense of loss by having a deduction of pay and would receive the equivalent of a small honorarium from the authority.

The help possible from a company is limited according to circumstances. It is perhaps more easily provided when it is restricted very largely to one college—as it is in the case of the company with which I am associated, owing to the centring of its educational effort in one place.

The sandwich scheme in operation at Rugby, a 'shift system', allows the teachers to link with industry during their 'non-teaching shift'. This side of the partnership has to develop with experience, but there seems no doubt that teachers will thus be able to benefit from some form of industrial experience, either in the research laboratory or with design engineers, service departments or in the factory.

In this, as in other directions, I strongly support the idea of a close partnership of outlook between industry and technical colleges.

Dr. J. E. Richardson: The figures which Dr. Willis Jackson has given concerning the need for teachers depend entirely on the validity of the figures given in the White Paper with regard to the required numbers of students. I estimate that by 1960–61, instead of the target number of 700 000 part-time day students, we shall only have some 500 000. Even so, if only this number was forthcoming some of us would not know what to do with them. The problem will be one of space rather than of teachers, and I am wondering whether adequate expansion is in fact taking place in sufficient of the existing colleges.

With regard to the question of release of members of staff to industry, paragraph 125 of the report asks for a more flexible arrangement concerning the money which industry might pay to the teacher while he is seconded to them, while Recommendation 17 uses the words 'retain any payments'. In view of the poor response, due largely, I believe, to financial limitation, may I suggest that the teacher might get the lot? Some years ago I had a visitor from the United States who was a teacher in one of the university institutions and who was enjoying a sabbatical year on full pay. He was concerned with aeronautics, and he told me that in his view, not only was industrial release both desirable and necessary, but that each year the aircraft company concerned found it essential to have teachers coming in, otherwise they would not be able to meet their programmes. I said, 'What about payment?' and he replied, 'We keep the lot,

obviously'. This emphasizes a difference in approach between the United States and this country.

There has been comment about the reluctance of teachers to go into industry; there is, in fact, some reluctance on the part of the technical colleges because of a tendency for there to be one-way traffic. Some teachers have gone to industry and have not come back.

In Recommendations 6 and 19 there are suggestions whereby existing teachers may be encouraged to improve their qualifications by secondment. We welcome these recommendations.

It is stated that there are not enough technical teachers coming through the technical teacher training colleges. Could not this be improved by applying the sandwich system? If a man in industry wishes to become a technical teacher, and if he is told that the best route is via one of these colleges, then he is likely to be put off by the one year's hiatus in which he becomes a student and is not earning. Would it not be better to put him into teaching straightaway on the understanding that he will be expected to go into a teacher training college on a six-month/six-month basis on full pay during his first two years of service?

Recommendation 5 makes reference to encouraging high-grade technical staff in industry to come into colleges as 'special lecturers'. Some of us do not like the word 'special'. It seems to disparage the rest of our teachers, and we would make the suggestion that the words 'associate lecturers' be substituted therefor.

Mr. F. P. B. Browning: My main purpose is to describe briefly the arrangements for advanced courses in engineering which are being worked out at the Rugby College of Technology under Principal Cooper. They deal with full-time sandwich courses for students in residence, and are the result of close day-to-day consultation with industry.

The courses show fine disregard for normal academic terms. The first 22-week spell of full-time study begins in the middle of August; the second in February, so that the College closes in the summer for one month only. Each full-time lecturer serves as a member of one of two teams into which the staff is grouped, has 22 weeks of intensive teaching in the year, and then, apart from relief teaching and tutorial work by correspondence, is free to carry out research, renew contact with industry, and catch up on holidays. The annual intake of well-qualified students is high, so that specialist staff can be employed efficiently with optimum numbers. It would appear that the system offers one means of reconciling those recommendations in the report which seem to be in conflict, i.e. the need to make full use of scarce teachers and the need to give them a reasonably light teaching load, with opportunity for research and return to industry.

It is realized that full-time members of staff will need the constant support of part-time teachers from industry on specialist subjects. We have already started to use the term 'Associate Lecturers' in Rugby, and are thinking of paying them a sessional fee or retainer to accord with their professional status.

I conclude by reference to what the White Paper calls the broad base of the pyramid, where technical colleges devote their energies to the training of the craftsman and the most important job of bringing up to date our forms of technician training. Many of the recommendations of the report, and the need for maximum help from industry, apply with equal force to this level of work, where there is still much experimentation to be done.

Mr. Maynard M. Boring: It is indeed a pleasure to meet with this group to discuss problems of education and to find that there is a great deal of similarity between the situation in Great Britain and the United States.

There are two factors that somewhat change the complexion of the problems. One is the great distances involved between many of our educational institutions and the large segments of industry, and the other, because of child-labour laws, is that our children go to school for longer periods than yours do. In fact, 92% of our children finish what we call high school at 18 years of age. We have a tendency to gear our education system to the average child, and are doing very little in arranging special programmes for the gifted.

There have been substantial changes in the education process in the United States during this past century. A large number (approximately 30%) of our young people enter some college or university after leaving high school. However, only about half of these finish the four years to obtain their initial degree at the age of 22.

There are a great variety of educational institutions in the United States, including over 1 700 schools of higher education, of which 206 grant degrees in engineering.

Recognizing the difficulties involved, particularly in the engineering and scientific areas, of alerting the 28 000 public school systems to the need for a sharpening-up of technical education, a manpower commission in engineering and one in science, representing all the various engineering and scientific bodies in the United States, were set up to develop public recognition of the importance of science and engineering. Recently President Eisenhower set up a Presidential Committee to work in this same field.

We are faced with exactly the same problems as you are in connection with the teaching profession. Last year the largest number of reasons, given by engineers who left the employ of the company that I represent, was to go into teaching. The numbers are small, but we are gradually developing a flow of well-qualified individuals from industry to the teaching profession.

One way being developed to assist in holding good teachers is a constantly growing retainership programme with industry. Teachers can be of substantial assistance to industry during their vacation periods. Many of our teachers are able, not only to augment their incomes, but actually to work with up-to-date engineering problems by this association. In fact, some of the better-known teachers are receiving more from their retainerships than they do by way of their regular salaries.

To enable teachers of our secondary schools to take advanced courses in the field of their specialization, and to encourage the teaching of science and mathematics in our public schools, several industries and recently our Government have established a large number of fellowship programmes.

The Academy of Sciences and others are conducting experiments in the teaching of mathematics, science and English by closed-circuit television. Results indicate that this method may have great possibilities. Psychological experiments indicate that the retention of information by television programmes may be better than from a normal lecture.

We, too, have a financial problem. The salaries of our educators are too low, and steps are being taken to rectify this situation. However, I feel a greater portion of this burden should be carried by industry than by the Government.

Alderman J. W. Brown: I think the keynote of this matter is partnership with industry. We have been prone in the past to use the word 'co-operation', but it has come out clearly that we must rely on industry more and more in these matters.

Another point which must not be overlooked is the quality of the teachers. We have far too much formal teaching in our technical colleges. It has given rise to a great amount of criticism, much of it unfair but much of it true. Many students are passive recipients of lecturers' notes, and it would be far better if there were fewer lectures and more time under the tutors' direction to do proper reading and study.

The problem of getting the partnership with industry goes further than is sometimes thought. It is not sufficient to import a representative of industry and to place him on the governing body. It is necessary to see that the governing body has the power—at least as much as the university—to spend within the estimates provided, and it is important that those representatives of industry should sit on the advisory committees. I have sat on three such committees in the past week, and to my great surprise one went on for three hours and the other three and a quarter hours. You have to give them power to make recommendations with regard to the curriculum, to equipment and to other matters. It is they who are really the deciding bodies on what should be done.

I regard libraries as being of the utmost importance. Instead of students concentrating on lecturers' notes, the teaching staff must be encouraged to show them how to make use of the library and current scientific literature. In this connection, I am not certain that we have not been too immersed in the implementation of the recommendations in the White Paper and elsewhere to see the position that is developing in the technical educational world. Technical colleges in the past have been regarded as a very poor second best to universities, but now they have a much more important part to play. We have not perhaps quite reached equality of status and parity of system with universities like the *technische Hochschulen*; but what has been developed is the specialist course for those who have been through a technical college or a university. These specialist courses are making a real contribution to industry, as they provide up-to-date information on all aspects of science and technology.

An important development in one college with which I am associated is that this year 49 graduates (in mathematics, physics and engineering) are taking a two-year course in their technical college on entering industry. For the first three months they attend the college full-time, and for the remaining period one or two days a week.

With the big increase in specialist courses I must stress once more the importance of the library. We must ensure that the teachers who come from the training colleges are accustomed to using the library. At the same time the librarian must be a member of the staff who sits on the board of studies.

The possibility of the development of an information service for industry was raised in the Ministry's circular, and the other day the question was raised whether industry really wanted it. In my own county, representatives of industry, Government Research Departments and the County Library are making arrangements for an information service based on the technical college libraries and are co-operating.

Mr. O. W. Humphreys: The thought of moving from industry to teaching must first arise in the mind of the man who is going to move, but there is no reason why minds should not be so conditioned that when such a thought arises it is regarded as in no way unnatural.

I would like to speak especially from the point of view of men working in industrial research. The first love of practically every physicist and engineering scientist is research, but the number of them who can find complete satisfaction in personal research throughout the whole of their working lives is very small—one wishes it were much larger. Very many, having put in twenty years or so on research, will inevitably find it increasingly hard to keep up with their younger colleagues, and yet the way to senior technical administrative positions—their natural alternative outlet—may well be blocked. This is very frustrating. The vision ahead is of another twenty years during which scientific leadership will increasingly be passing to the succeeding generation. Most of these men would find that, by transferring to work of a completely different kind, they could enjoy a second very satisfying career. Many already do so, moving within their own firms into the development laboratories, the factory or the commercial department, but to some such occupations are not attractive. Amongst these people there are undoubtedly many who would make admirable teachers, who would enjoy teaching, and who, by transferring to it, would lead much fuller lives. The report states that industry must be prepared to make sacrifices to solve this problem. I agree, but here is a way in which industry can collaborate without making sacrifices; in which industry, the colleges and the individual all gain. We can help by bringing men up to regard this second phase in their life as a natural thing, and not in any sense as an indication of failure in the career of their first choosing.

Mr. H. S. Barlow: The report outlines desirable conditions of service for teachers in technical colleges which must be created before recruitment can be stimulated. These, however, cannot be created until the teachers are recruited in adequate numbers and quality. It seems to me that the first step must be taken by local authorities to set up college staff establishments adequate in numbers and grading to permit reasonable teaching timetables, research, secondment to industry and those other desirable features outlined in the report. Then a major item in the problem of recruitment is the need for greater imagination in publicity and advertising.

Circular 305, unfortunately supported by the Committee as offering a solution to the problem, lays down a four-tier classification of technical colleges and is, in my opinion, the one method guaranteed to reduce the recruitment of qualified people into technical teaching, except into a few advanced colleges. Many colleges, which by virtue of their past service and successes deserve better treatment, have been down-graded. The Ministry may deny this, but in the eyes of students, parents and teachers, both present and future, this is true, and in the problem of teacher recruitment and retention this is what matters.

Already we have a condition in which staff in the down-graded area colleges are seeking and obtaining posts in regional colleges and colleges of advanced technology, not with the idea of improving salaries, but to obtain status in posts of equivalent grading and a desire to be associated with full-time courses. The area college, without the leaven of advanced and full-time or sandwich courses, offers little attraction to qualified teachers and possible recruits from industry. Memorandum 545 is also restricting the freedom of technical teachers in a way which would not be tolerated in the universities. At a time when the situation is crying out for centres of expansion the policy seems to be one of strategic retreat.

Mr. C. Jameson: One has been conscious throughout the discussion that very careful emphasis has been laid upon co-operation with industry and full use of the teaching manpower which is available to us, and one cannot disagree with any of that; but we may be missing one very important thing. If the proposals contained in the White Paper dealing with the expansion of technical education are implemented—even in part only—it will mean that classes in technical colleges will contain a greater variety of ability and aptitude than before.

Technical teachers must now realize that there is a greater element of compulsory attendance in our classes, and from now on the teaching methods, the approach, the sympathy and the understanding of the teacher for his students are going to be far more important than before.

In Garnett College we have endeavoured to give breadth to our training so that we take the person, his knowledge of his subject and his experience, and we try to show him how they can all be used in the development of teaching methods in the classroom. Subject-matter is very important, but for young

people the approach, the sympathy and understanding of the teacher are equally important.

What is happening at the moment as far as technical teacher training is concerned? It is treated as the responsibility of the individual. If a man wants to train to become a teacher in a technical college, he has to give up his job in industry and his salary and enter a training college on a grant. Secondly, he may have to give up service considerations. Thirdly, he receives no specific reward for the fact that he is a trained teacher. Also, if a man comes to Garnett College for in-service training, what must he do? He must be prepared to have crowded into four days a week the same number of teaching hours as he would have in a five-day week in order that he can be released on one day a week.

At the present time there are approximately 130 students in Garnett College, of which about 50% have either university degrees or degree equivalents or the final examination of a professional body. The rest have the highest qualification obtainable in their technology or craft, and all have at least four years' experience in industry beyond the age of 21 years.

The Willis Jackson Committee has recognized the value of teacher training, and that more must be done to ensure a greater efficiency of the new teacher and the serving teacher.

Mr. A. H. Albu, M.P.: As I am a member of the Opposition Party it is easy for me to say that what is needed is that the Government should spend a great deal more money! I am afraid that is the main conclusion from the discussion, although there were a number of very interesting contributions. I particularly liked the one suggesting the possibility of late entry into teaching after a man has passed his most prolific period of research activity.

The only thing I can add, after thinking about the problem of attracting teachers, is that I wonder whether enough has been made of the advantages of being a teacher? In this connection, I know there is a great deal in the report, which some of the teachers here have supported, about the importance of providing enough teachers and sufficiently large establishments in order to carry out the recommendations for 'free time' for activities other than teaching. One of my own sons said to me that the advantages are not all in going into industry, especially if you happen to have come from a university where you have been used to a cultured atmosphere, a fairly broad range of subjects and people to talk to and a considerable amount of time in which to do other things such as travelling abroad. The graduate who comes down from university and goes into industry is fortunate if he gets three weeks' holiday a year, probably confined to the time when the works are closed, and he finds the opportunities for cultural activities are severely limited. I think, therefore, that we should do more to publicize the opportunities of a more varied life which can be enjoyed by the teacher.

Reference has been made to the sabbatical year. Personally I think that would be a jolly good thing not only for teachers but also in industry. I understand that there is one large company which is doing that with its senior staff, and it is being done in the United States. It might not be a full sabbatical year but perhaps a sabbatical quarter. I do not think that the question of attracting teachers is entirely one of salary; for teaching is the sort of life which sometimes attracts a person different from the one who would be satisfied in industry.

Sir Hugh Linstead, M.P.: In following my colleague, Mr. Albu, I do not find it any more difficult than he does to say that the answer lies in Government spending more money, but I am not sure that he and I, having said that, have said very much. I hope you will bear in mind that if what The Institution of Mechanical Engineers calls the 'swing of the pendulum' ever takes place, Mr. Albu's words may be brought home to him!

I have found this a most satisfying discussion, but I do not believe that there is one solution. It consists, as the discussion has shown, in breaking the problem up into pieces and pressing everywhere. There is, for example, the greater use of women in teaching, which has not been mentioned. There is also the need to make science and technology more popular in some of our older schools, which still have the arts tradition close to heart. There are in fact many different ways in which contributions can be made to improving conditions and attracting recruits.

It seems to me that one of the great advantages of this report is that at long last some sort of yardstick has been established. Here is a guide which can be looked at in four or five years' time to see whether the actual teaching of technology corresponds to what the report says it should. If then we still find ourselves short of technologists and teachers, we shall know we are faced with a major national crisis, because this country has little except its scientific wits to live on, and it will be a major national tragedy if we are unable to get the technologists and teachers in order to be able to do that.

It may be found in five years' time necessary to go back to the Government and to say, for example, that you cannot go on pouring out grants to students without attaching conditions as to the institutions or technologies for which they would be available. One would hope not to see such a condition arising, but at least the report will be a yardstick by which we can recognize it.

Mr. A. A. Part: As you have heard from the Minister, our task is to study the points which have been made. It seems to me that some interesting boats have been pushed out, not all perhaps taking part in the same event, but in one way or another they form a fairly impressive armada.

I should like to mention one contributor who has taken part in the main event, and that is Mr. Boring, who made a number of remarks in that modest way which, in my experience, is so characteristic of Americans. He mentioned television, and I shall not follow him into that field; but I would say that in my view there is room for research into what I think is called in the United States the 'learning process'. I believe it is particularly true of our technical education, especially at the levels which are concerned with the teaching of technicians and craftsmen. I am not at all sure that the teaching methods which we adopt at present are necessarily always the best.

I should also like to say that we greatly appreciate the presence of two Members from the House of Commons. There are few things which can do us more good than the informed interest of Members of Parliament. We cannot have too many allies in this business.

There is one point about science teachers which Dr. Willis Jackson made and which I should like to take up, because, although he correctly pointed to the seriousness of the situation, I think that he perhaps painted it a little darker than is the case at present. Not everybody realizes that the number of science teachers in the schools is increasing year by year: two years ago the number rose by 200, one year ago by 300 and last year by 500. Still more striking are the results which are being achieved by science teachers who are on the job. Between 1951 and 1956 the number of passes at the advanced level of the G.C.E. in chemistry, physics and mathematics increased by 34%, 47% and 55% respectively. I think that is a great compliment to the science teachers in spite of their difficulties and small numbers. It has quite dramatic implications for the availability of skilled manpower in the country.

To the report itself I can add one piece of information. It is that the Minister has accepted the recommendation that a Standing Advisory Committee should be established to deal with technical teachers, and steps are being taken to set up that committee. We hope that Dr. Willis Jackson will be the Chairman.

On training, it will have been clear to you that some far-reaching decisions are being asked for from the Ministry. We have been doing quite a lot of homework on this and indeed on the whole report.

With regard to supply, very clearly there is no single solution. We have no immediate new source of teachers such as was provided, for example, by ex-Servicemen after the war for the emergency training scheme. Therefore, we must take advantage of every opportunity which occurs, including releases which will be taking place from the Services in the near future. I hope that before long the Ministry will be able to express a view on supply and recruitment problems as well.

On the question of governing bodies of technical colleges, we hope to issue guidance to local education authorities soon. The only reason we have not done so before was we thought we had bombarded them with so much paper in the last eighteen months on the subject of technical education that we ought to give them a rest. Our guidance will emphasize the importance, not only of industrialists serving on governing bodies, but also of seeing that they have a worth-while job to do when they get there.

The Minister himself is much attracted by the idea that teachers should have opportunities to do research and consultant work, and I am sure this is something we shall be encouraging as time goes on. I was interested to hear all that was being done at Rugby, and it was helpful that Mr. Davies was able to give an account at first hand.

I believe there is one feature of our general campaign which is going to have implications very much wider than have been generally realized. I refer to the sandwich course. I believe that when we really get sandwich courses going we shall be finding all sorts of repercussions, in particular the personal contacts which are set up between colleges and industry. The Principal of one of the colleges of advanced technology made an interesting remark to me. He said, 'The Dip. Tech. is driving my teachers out to visit industry'. I said, 'Why have not they been there before?', and he replied 'You do not necessarily have to go out to industry in order to teach a degree course in engineering'. These people are being invited by firms to serve on selection panels, and one can see how personal contact is set up in this and other ways.

There is so much that is good in the Willis Jackson Report that I hope the fact that there is inevitably a good deal of official reticence at this juncture will not suggest that the Minister does not appreciate the report. It is a landmark in the history of technical education, and the Minister hopes to have decisions to announce before long. Those who had the privilege of working with this Committee when it was preparing the report are conscious of the particular debt that we owe to Dr. Willis Jackson.

Mr. G. W. Kingaby (*communicated*): The report assumes the increase in the annual output of students from advanced courses visualized in the White Paper. Except in the field of degree courses there is, at present, no evidence of any increase. The increase in the numbers of students taking degree courses may be due to the increase in the numbers in the science sixth forms in grammar schools. Thus, whilst the grammar schools seem to be playing their part, it would appear that the release of students by industry shows no appreciable change. Industry has not yet accepted the idea of sandwich courses.

The White Paper numbered an output of 9 500 students from advanced courses in 1955–56. By careful study it is estimated that more than 8 000 of the 9 500 students were attending part-time day courses leading to a degree or to a Higher National Certificate. 'An increase in the annual output of students from advanced courses, mainly from full-time and sandwich courses, from 9 500 to 15 000 is visualized'. The full-time degree courses in technological subjects, in general, are full; hence this increase can come only from an increase in the numbers of students taking sandwich courses.

It is significant that the British iron and steel industry boast that they were the first industry to approach a technical college about sandwich courses for their employees; perhaps the education and personnel officers of other large industrial organizations intend to make similar inquiries. It is essential that sandwich courses coupled with the Diploma in Technology should be given the full support of industry. It is imperative that this support be given immediately if the scheme is not to die before the training of the large numbers, now in the secondary schools, is imminent.

There are many industries employing few personnel, for whom the release of their employees for six months is not possible without disrupting their internal economy both productively and financially; such industries will continue to favour part-time day courses. A collective scheme of training should be prepared where the student is employed by different participating firms during the period of his sandwich course; the details of such a scheme may be difficult to arrange on a strictly equalitarian basis, but it is essential.

By all means go ahead with schemes to increase the numbers of trained teachers in technical colleges, but the attraction of many more students taking sandwich courses should be a first consideration. In my opinion only by the co-operation of industry and the technical colleges can the increase visualized in the White Paper be achieved.

Prof. E. W. Marchant (*communicated*): I remember a saying of the late Dr. Barnes, 'Those who can, do; those who can't, teach'. He said of himself that he went one step further, for, after being a professor at the Manchester College of Technology, he became head of T Branch in what was then the Board of Education, and therefore had to try and teach the teachers. I am very proud of the fact that the senior officer in T Branch of the Ministry of Education is a graduate of the University of Liverpool. There seem to me to be two essential requirements for any teacher in a college of technology besides being a really well-educated man: he must have a firm grasp of the fundamental principles underlying the technology he has to teach, and he must be conversant with the latest developments in the practice of that technology, i.e. he must know all about the construction and working of the equipment used. The kind of instruction that is wholly useless is that typified by a rhyme about a pump that I remember, 'H is the handle, S is the spout, O is the hole where the water comes out'.

Dr. Willis Jackson (*in reply*): In view of the special responsibility carried by the Ministry of Education in respect of the Committee's recommendations, it was very appropriate that Mr. Part should speak at the end of the discussion, and I have little to add to his remarks. As he mentioned, I am to have the opportunity of pursuing the matter through the new Advisory Committee, and what has been said this evening will be of considerable value to this Committee, as it attempts to deal with a number of questions not fully explored in the report.

In particular the emphasis which we laid on the recruitment of graduate scientists and technologists for teaching at the advanced and intermediate levels of professional courses may perhaps have given the impression that we do not attach comparable importance to the needs of the courses provided for technicians and craftsmen. These needs call for much more attention than we were able to give them in our concern to issue the report as quickly as possible.

It is evident that there is no single, nor simple, solution to the many problems discussed in the report, but the growing sense of partnership revealed this evening is an encouraging and promising augury of rapid progress. From now on let there be more action rather than more words.

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The Institution of Electrical Engineers
Paper No. 2423 S
Feb. 1958
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PARALLEL OPERATION OF TWO SYNCHRONOUS MACHINES

By J. H. WALKER, M.Sc., Ph.D., Member, and N. KERRUISH, M.A.

(*The paper was first received* 15*th April, in revised form* 14*th June, and in final form* 26*th July*, 1957.)

SUMMARY

The paper derives the equations required in the prediction of the steady-state characteristics of an alternator supplying a synchronous motor, which is of particular interest in electric ship propulsion. These equations are valid for any degree of saliency and any value of synchronous reactance in either machine. Since considerable labour is required in the numerical evaluation of the equations, the power, terminal voltage, armature current and pole angles at pull-out, as functions of the machine synchronous reactances, are given in the form of tables or families of curves. A curve is given showing the variation of the pull-out power with saliency, and another shows the extent to which the pull-out power of a combination of two machines is reduced in comparison with the values which would be obtained if either machine were running on an infinite busbar.

LIST OF SYMBOLS

δ = Pole angle of machine, degrees.
V_0 = Per-unit internal voltage of machines.
X_d = Per-unit direct axis synchronous reactance.
X_q = Per-unit quadrature-axis synchronous reactance.
Subscripts 1 and 2 refer to machines 1 and 2, respectively.
ϕ = Power-factor angle, degrees.
V = Per-unit terminal voltage.
I = Per-unit armature current.
P = Per-unit power.
$\alpha = X_{d2}/X_{q2}$.

$$\beta = \frac{X_{d1}}{X_{q1}} - 1.$$

$$\gamma = \frac{X_{d2}}{X_{q2}} - 1.$$

Primes denote pull-out values, e.g. δ_1' is the value of δ_1 at pull-out.

(1) INTRODUCTION

The problem of predicting the steady-state performance of a synchronous machine operating in parallel with a so-called infinite grid has been the subject of much technical literature and to-day may, for all practical purposes, be considered as solved.[1–4]

The analysis of the steady-state performance of two duplicate cylindrical-rotor machines operating in parallel is simple, and references have been made to this in some of the literature.[3,4] The two machines will, however, normally differ either in the value of their respective synchronous reactances, X_d, or in the construction of their rotors. The latter feature will result in differing values of the ratio between the direct-axis and quadrature-axis synchronous reactances, X_d/X_q. There is the further possibility, of course, of the machines differing in their values of both X_d and X_d/X_q. It seems that no analysis has yet been published for these particular conditions, and the paper therefore gives a complete solution of the whole problem of the steady-state operation of two synchronous machines.

The problem has some importance in a number of applications of which the following are typical examples.

(1.1) General Case

It sometimes arises in practice that one synchronous motor may form a large fraction of the total load on a station. If the motor is normally operating a 24-hour duty, e.g. in a rolling mill, the disconnection of the normal day load, accompanied by a shutting-down of generating sets supplying the busbars, may result in a state of affairs approximating very closely to the two-machine combination. This may involve a dangerous reduction in the pull-out power of the motor and thus requires careful investigation.

(1.2) Electric Ship Propulsion[5]

The normal arrangement for electric ship propulsion is to have one double-unit synchronous motor driving a propeller shaft, this motor being supplied by one turbo-alternator. In the case of multi-propeller ships the above arrangement still holds, but when operating the ship at reduced speed it may be more economical to operate two motors from one turbo-alternator. Since a sharp application of the helm or heavy seas may impose overloads on the propeller motor, an accurate knowledge of the pull-out power of a given combination of machines under all possible circumstances is of importance.

(2) ASSUMPTIONS

The following assumptions are made in the analysis:

(*a*) All load changes take place within a time interval longer than the short-circuit transient time-constant of the machine. The analysis in the paper is thus restricted to steady-state conditions as defined by this assumption.

(*b*) Magnetic saturation can be neglected.[6]

(*c*) The field current is set at the value corresponding to operation at rated load and maintained at this value up to the pull-out point.

(3) SCOPE OF THE TABLES AND CURVES

The following three combinations of two synchronous machines are considered:

(*a*) Two cylindrical-rotor machines.

(*b*) One cylindrical-rotor machine with one salient-pole machine.

(*c*) Two salient-pole machines.

These three main groups are further subdivided, as shown in Table 1, according to the respective values of X_d/X_q.

In the case of two machines of dissimilar types a further subdivision is required, since when the combination is operating at power factors other than unity the pull-out torque depends on which of the two machines is over-excited (lagging power factor) and which is under-excited (leading power factor). This further subdivision is also shown in Table 1.

It can be seen from Table 1 that for the turbo-alternator with a cylindrical rotor it is assumed that $X_d/X_q = 1$. Nevertheless, some turbo-alternators, owing to the effects of rotor slotting, exhibit a slight saliency effect with X_d/X_q a few per cent in excess of unity. To cover these conditions machines with saliencies corresponding to $X_d/X_q = 1{\cdot}05$ are considered in cases 3(*a*) and 3(*d*) in Table 1.

Written contributions on papers published without being read at meetings are invited for consideration with a view to publication.
Dr. Walker and Mr. Kerruish are with the British Thomson-Houston Co., Ltd.

Table 1

COMBINATIONS OF MACHINES WITH FIGURE AND TABLE NUMBERS

Case	Type of machine		X_d/X_q		Power factor	Excitation		Table number	Figure numbers	
	Machine No. 1	Machine No. 2	Machine No. 1	Machine No. 2		Machine No. 1	Machine No. 2	Pull-out power	Voltage current, and power factor	Pole angles
1	C.R.	C.R.	1·0	1·0	1·0	Equal		4(*a*)	5	14
	C.R.	C.R.	1·0	1·0	0·9	Over	Under	4(*b*)	6	15
	C.R.	C.R.	1·0	1·0	0·5	Over	Under	4(*c*)	7	16
2	S.P.	C.R.	1·6	1·0	1·0	Equal		4(*d*)	8	17
	S.P.	C.R.	1·6	1·0	0·9	Over	Under	4(*e*)	9	18
	S.P.	C.R.	1·6	1·0	0·9	Under	Over	4(*f*)	10	19
	S.P.	C.R.	1·6	1·0	0·5	Over	Under	4(*g*)	11	20
	S.P.	C.R.	1·6	1·0	0·5	Under	Over	4(*h*)	12	21
3 (*a*)	S.P.	S.P.	1·05	1·05	1·0	Equal		4(*j*)	—	—
	S.P.	S.P.	1·05	1·05	0·9	Over	Under	4(*k*)	—	—
	S.P.	S.P.	1·05	1·05	0·5	Over	Under	4(*l*)	—	—
3 (*b*)	S.P.	S.P.	1·6	1·6	1·0	Equal		4(*m*)	—	—
	S.P.	S.P.	1·6	1·6	0·9	Over	Under	4(*n*)	—	—
	S.P.	S.P.	1·6	1·6	0·5	Over	Under	4(*p*)	—	—
3 (*c*)	S.P.	S.P.	2·5	2·5	1·0	Equal		4(*q*)	13	22
	S.P.	S.P.	2·5	2·5	0·9	Over	Under	4(*r*)	—	—
	S.P.	S.P.	2·5	2·5	0·5	Over	Under	4(*s*)	—	—
3 (*d*)	S.P.	S.P.	1·6	1·05	1·0	Equal		4(*t*)	—	—
	S.P.	S.P.	1·6	1·05	0·9	Over	Under	4(*u*)*	—	—
	S.P.	S.P.	1·6	1·05	0·9	Under	Over	4(*v*)	—	—
	S.P.	S.P.	1·6	1·05	0·5	Over	Under	4(*w*)	—	—
	S.P.	S.P.	1·6	1·05	0·5	Under	Over	4(*x*)	—	—

C.R. = Cylindrical-rotor machine.
S.P. = Salient-pole machine.
* See also Fig. 4.

In the true salient-pole machine $X_d/X_q = 1\cdot6$ is probably the value most frequently encountered in practice and this is therefore considered in cases 2, 3(*b*) and 3(*d*). An extreme value of X_d/X_q, occasionally encountered in practice, is 2·5, and this is considered in cases 3(*c*). With these four values of X_d/X_q, namely 1·00, 1·05, 1·60 and 2·50, reasonably accurate interpolation can be made for other values.

Operating characteristics of combinations outside the range of the data listed in Table 1 can be calculated in detail from the equations given in the Appendices.

(4) VECTOR DIAGRAMS

(4.1) Two Cylindrical-Rotor Machines (Case 1, Table 1)

The vector diagram shown in Fig. 1 is for two cylindrical-rotor machines with equal synchronous reactances operating at unity power-factor.[4] In this case V represents rated common voltage at rated load current I, so that IX_{d1} and IX_{d2} represent the two synchronous-reactance voltages; the two vectors V_{01} and V_{02} closing these two triangles thus represent the internal voltages and, with no saturation, also the field currents at rated load. As the load on the combination is increased beyond rated load the reactance vectors increase to $I'X_{d1}$ and $I'X_{d2}$, the terminal voltage falling to V'. As the load increases, the product $I'V'$ increases to a maximum, and any attempt to increase the load beyond this point will result in the two machines falling out of step.

In each machine an increase in load is accompanied by an increase in the pole angles δ_1 and δ_2 to δ_1' and δ_2', in each case the internal e.m.f. vectors being assumed to coincide with the pole axes of the machine.

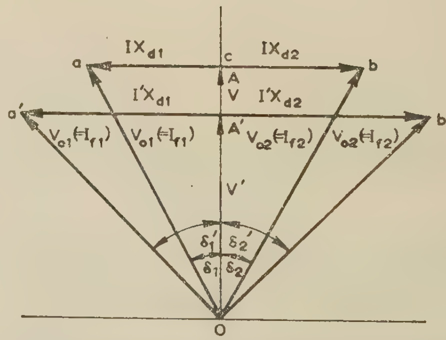

Fig. 1.—Vector diagram for two cylindrical-rotor machines.

The equations required to calculate the values of pull-out power, V', I' and δ' are given in Appendix 11.1.

(4.2) One Cylindrical-Rotor Machine with One Salient-Pole Machine (Case 2, Table 1)

In the vector diagram for case 2 of Table 1, shown in Fig. 2, the salient-pole machine is assumed to be over-excited (lagging power factor) and the cylindrical-rotor machine to be under-excited (leading power factor). This diagram is generally similar to Fig. 1, except that the reactance-voltage vectors IX_{d1}, IX_{d2}, and $I'X_{d1}$, $I'X_{d2}$, instead of being perpendicular to the terminal-voltage vectors V and V', are inclined by angles ϕ and ϕ', where $\cos\phi$ is the power factor at rated load and $\cos\phi'$ is that at the pull-out point.

A further difference between Figs. 1 and 2 is, of course, the

necessity of completing the voltage-vector triangles for the salient-pole machine by means of the reluctance semicircles as shown.[1]

The calculation of the power, current, voltage, power factor and pole angle is carried out from equations derived in Appendix 11.2.

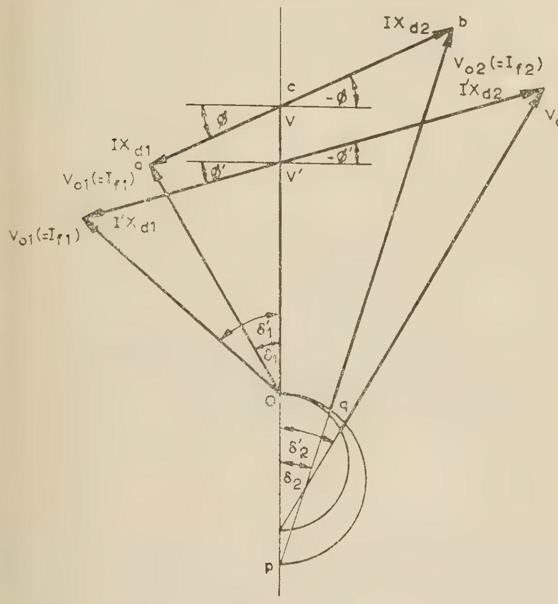

Fig. 2.—Vector diagram for one cylindrical-rotor and one salient-pole machine.

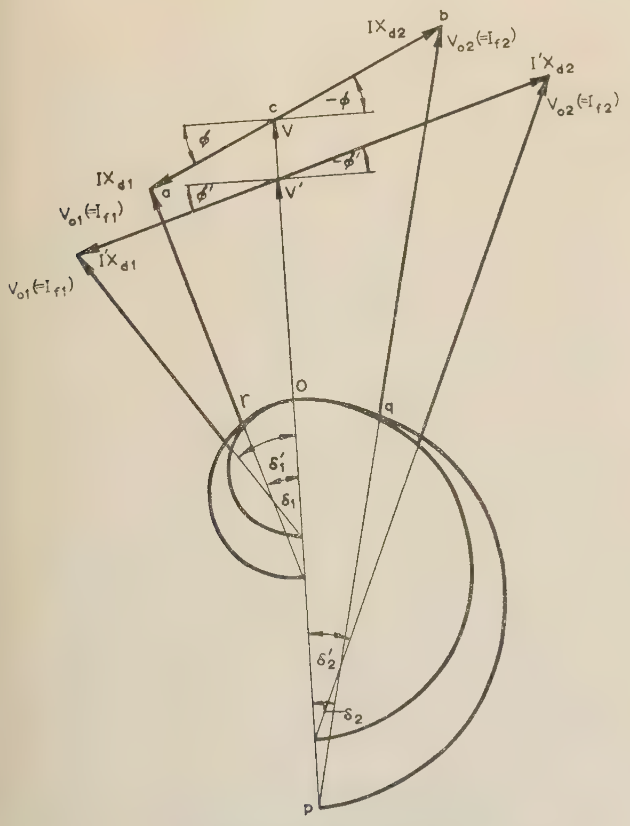

Fig. 3.—Vector diagram for two salient-pole machines.

(4.3) Two Salient-Pole Machines (Case 3, Table 1)

The vector diagram for case 3 of Table 1, shown in Fig. 3, is very similar to that of Fig. 2, except that here the reluctance semi-circles are required for both machines.

The equations for calculating the characteristics at the pull-out point are given in Appendix 11.3.

(5) DISCUSSION OF THE TABLES AND CURVES

The values shown in Table 4 and Fig. 4 give the pull-out power for all combinations of types of machines and, in a given combination, for all the relative synchronous reactances likely to be encountered in practice. The less important data con-

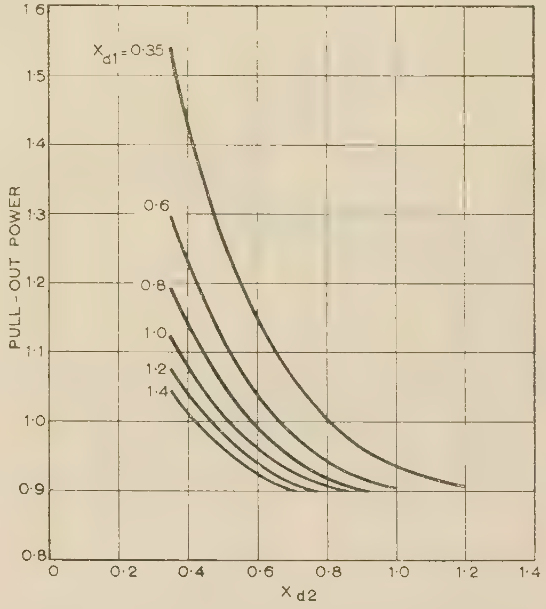

Fig. 4.—Pull-out power for two salient-pole machines at 0·9 power factor.

$X_{d1}/X_{q1} = 1\cdot6$ (over-excited).
$X_{d2}/X_{q2} = 1\cdot05$ (under-excited).

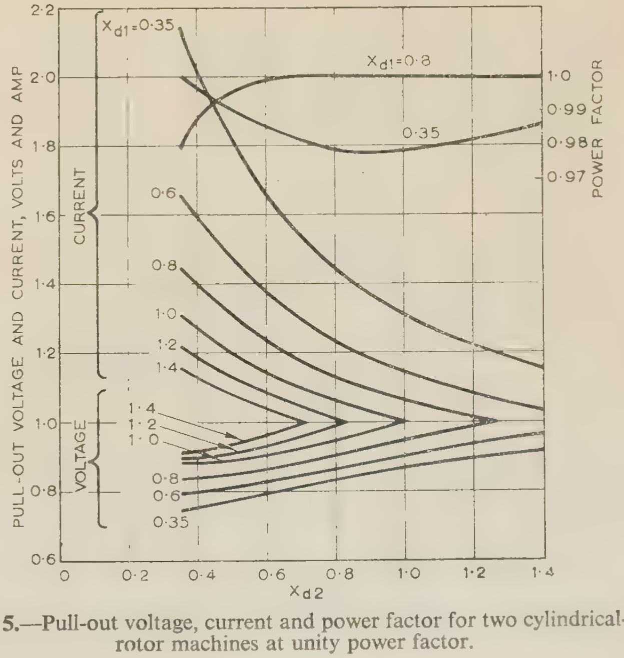

Fig. 5.—Pull-out voltage, current and power factor for two cylindrical-rotor machines at unity power factor.

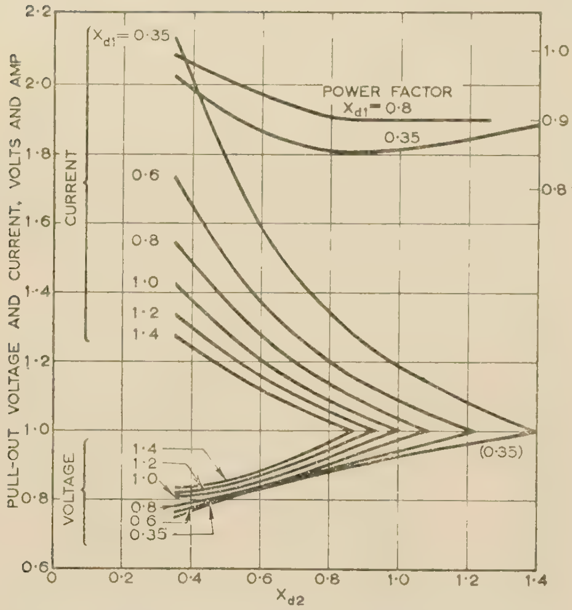

Fig. 6.—Pull-out voltage, current and power factor for two cylindrical-rotor machines at 0·9 power factor.

X_{d1} = Over-excited machine.

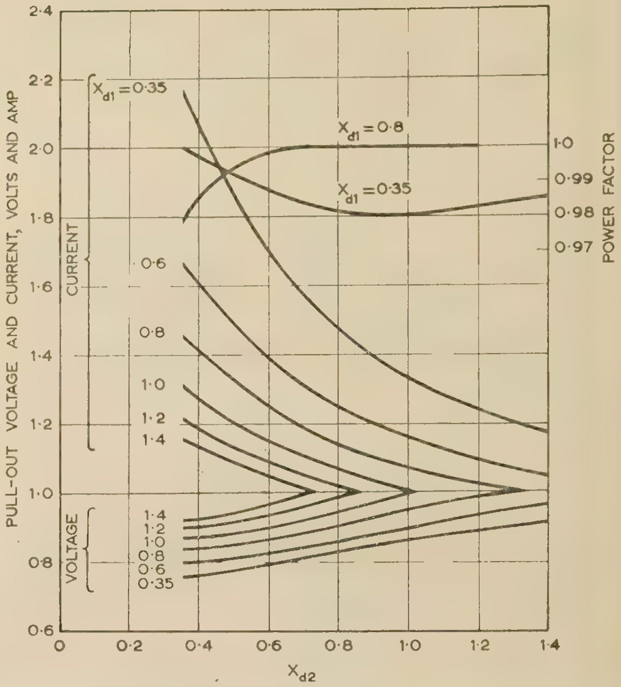

Fig. 8.—Pull-out voltage, current and power factor for cylindrical-rotor and salient-pole machines (X_d/X_q = 1·6) at unity power factor.

X_{d1} = Cylindrical-rotor machine.
X_{d2} = Salient-pole machine.

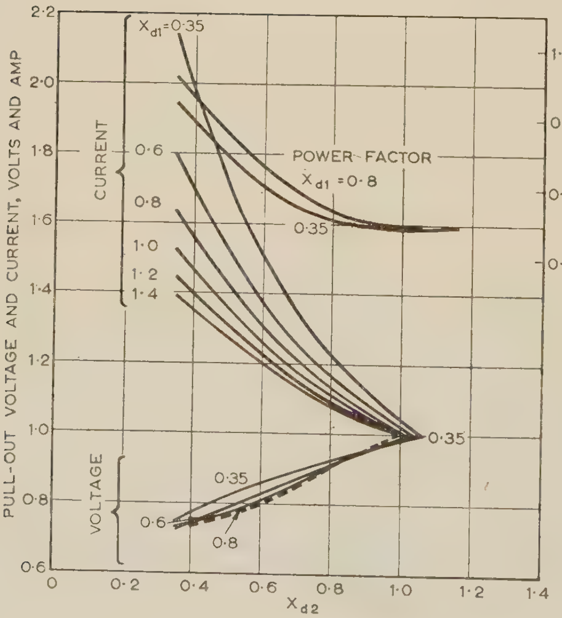

Fig. 7.—Pull-out voltage, current and power factor for two cylindrical-rotor machines at 0·5 power factor.

X_{d1} = Over-excited machine.

The dotted curve represents X_{d1} = 1·0, 1·2, 1·4, which are indistinguishable on this scale.

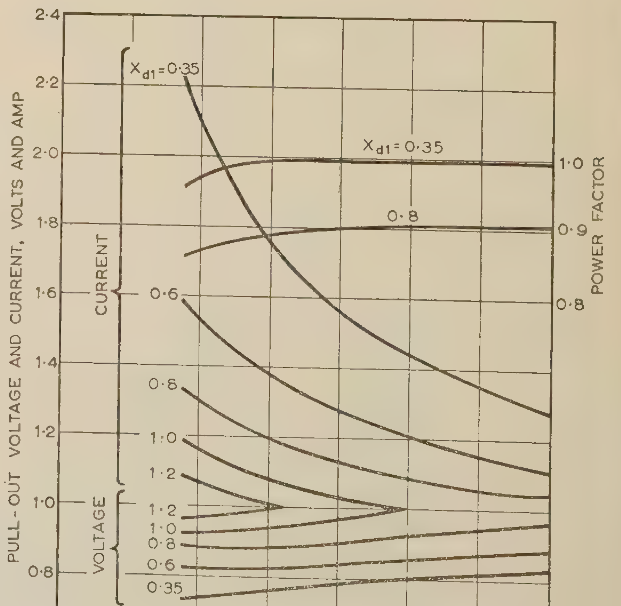

Fig. 9.—Pull-out voltage, current and power factor for cylindrical-rotor and salient-pole machines (X_d/X_q = 1·6) at 0·9 power factor.

X_{d1} = Cylindrical-rotor machine (under-excited).
X_{d2} = Salient-pole machine (over-excited).

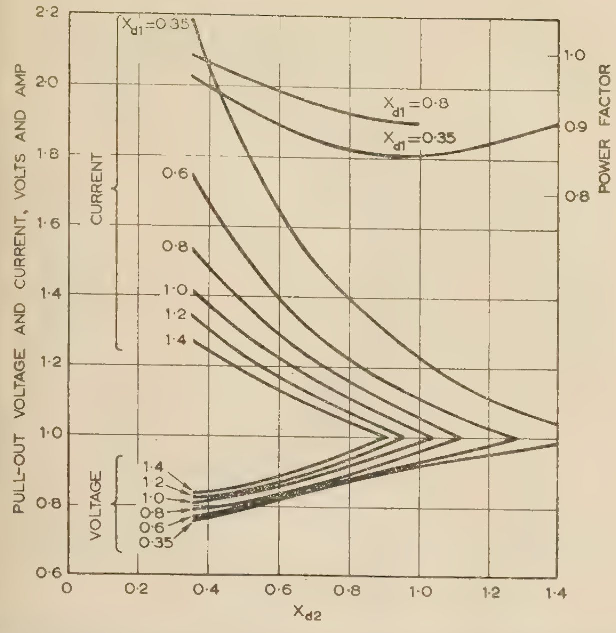

Fig. 10.—Pull-out voltage, current and power factor for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1\cdot6$) at 0·9 power factor.

X_{d1} = Cylindrical-rotor machine (over-excited).
X_{d2} = Salient-pole machine (under-excited).

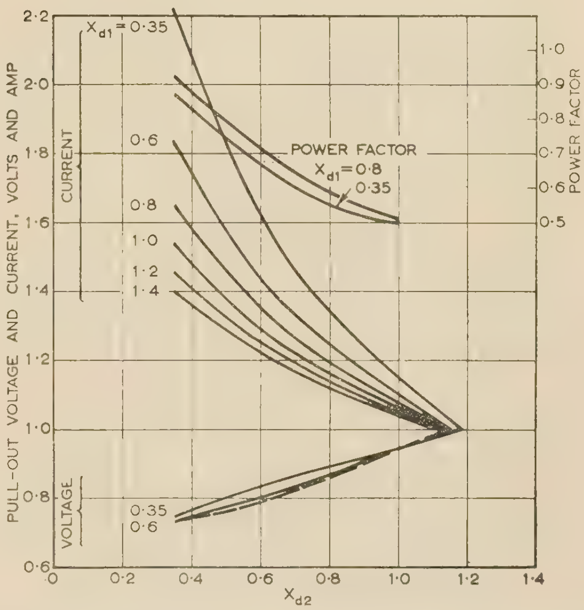

Fig. 12.—Pull-out voltage, current and power factor for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1\cdot6$) at 0·5 power factor.

X_{d1} = Cylindrical-rotor machine (over-excited).
X_{d2} = Salient-pole machine (under-excited).

The dotted curve represents X_{d1} = 0·8, 1·0, 1·2, 1·4, which are indistinguishable on this scale.

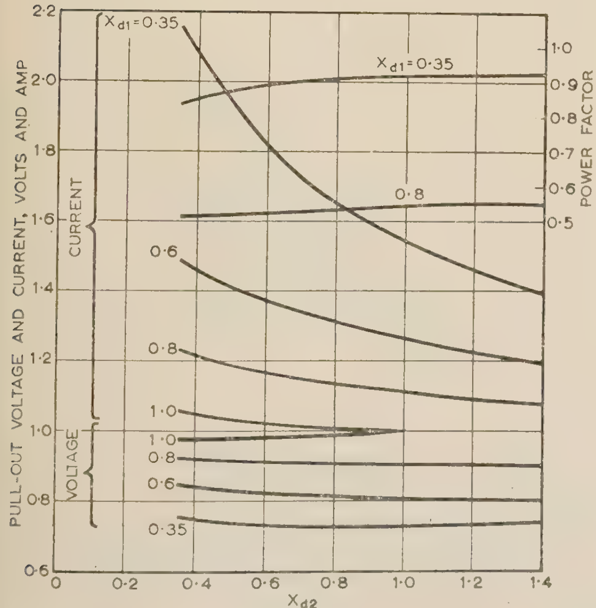

Fig. 11.—Pull-out voltage, current and power factor for cylindrical rotor and salient-pole machines ($X_d/X_q = 1\cdot6$) at 0·5 power factor.

X_{d1} = Cylindrical-rotor machine (under-excited).
X_{d2} = Salient-pole machine (over-excited).

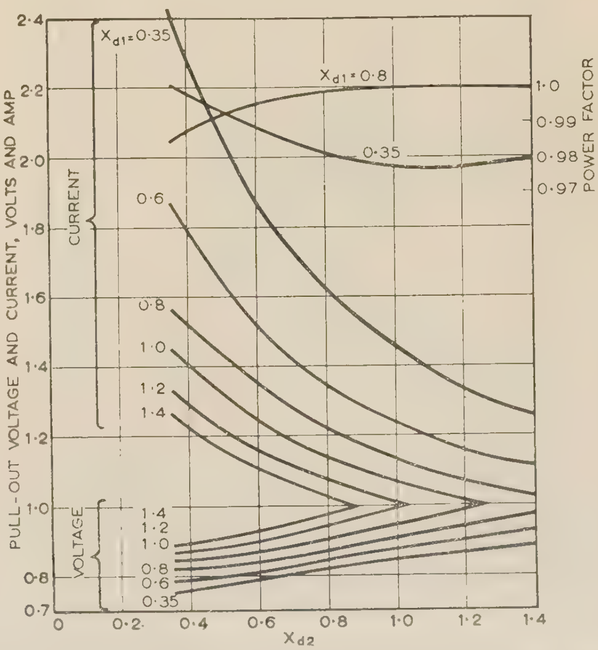

Fig. 13.—Pull-out voltage, current and power factor for two salient-pole machines both with $X_d/X_q = 2\cdot5$ at unity power factor.

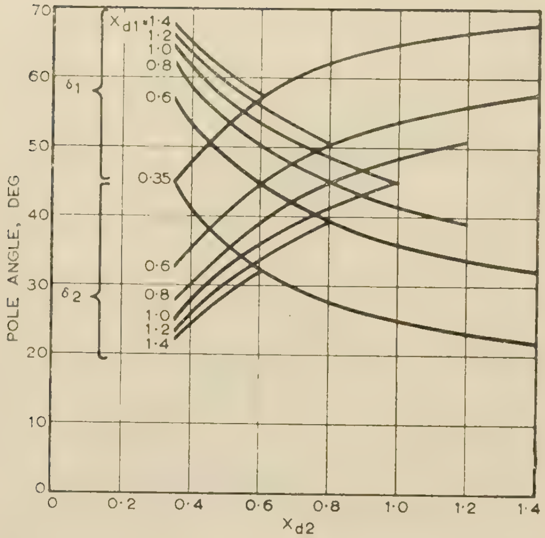

Fig. 14.—Pole angles at pull-out for two cylindrical-rotor machines at unity power factor.

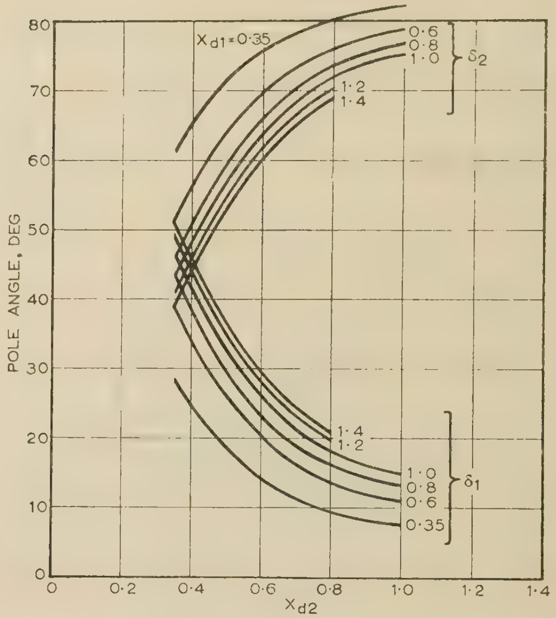

Fig. 16.—Pole angles at pull-out for two cylindrical-rotor machines at 0·5 power factor.

X_{d1} = Over-excited machine.

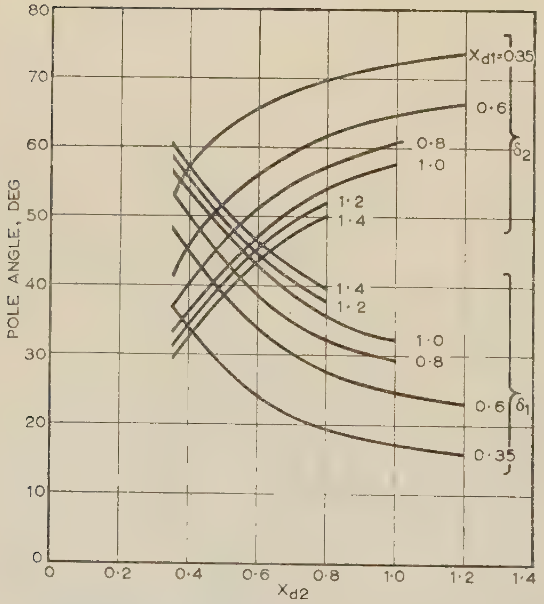

Fig. 15.—Pole angles at pull-out for two cylindrical-rotor machines at 0·9 power factor.

X_{d1} = Over-excited machine.

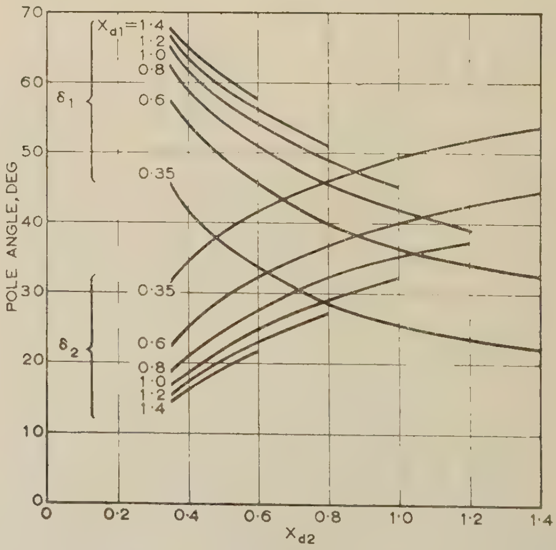

Fig. 17.—Pole angles at pull-out for cylindrical-rotor and salient-pole machines (X_d/X_q = 1·6) at unity power factor.

X_{d1} = Cylindrical-rotor machine.

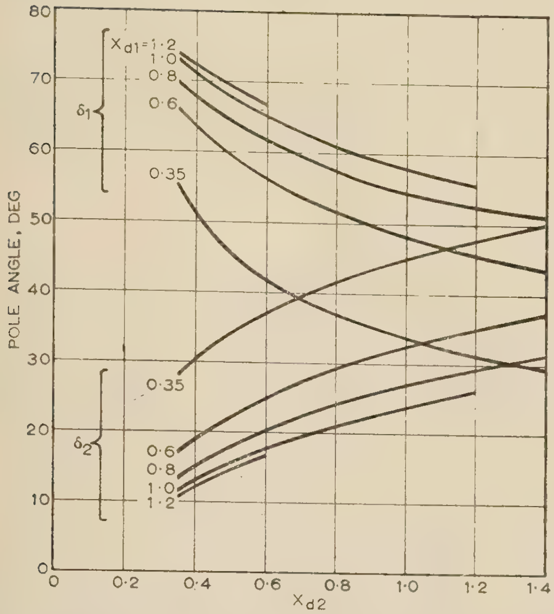

Fig. 18.—Pole angles at pull-out for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1 \cdot 6$) at 0·9 power factor.

X_{d1} = Cylindrical-rotor machine (under-excited).

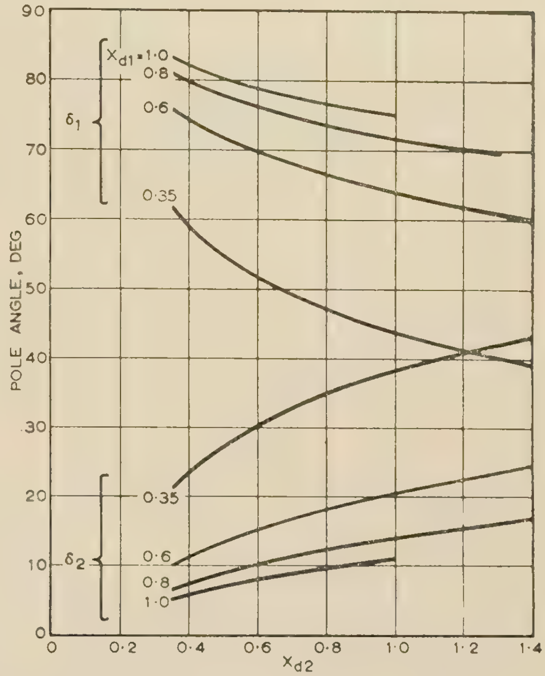

Fig. 20.—Pole angles at pull-out for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1 \cdot 6$) at 0·5 power factor.

X_{d1} = Cylindrical-rotor machine (under-excited).

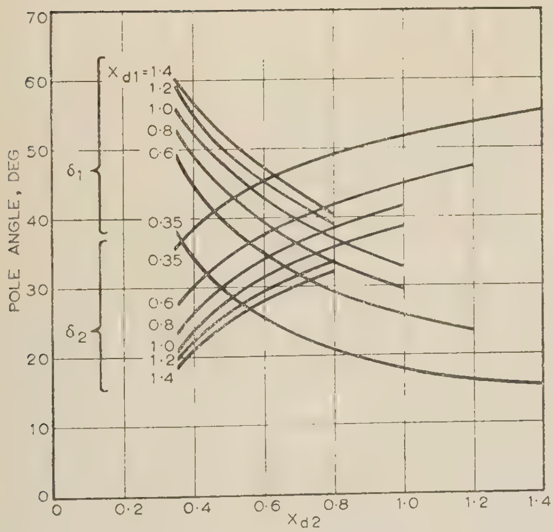

Fig. 19.—Pole angles at pull-out for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1 \cdot 6$) at 0·9 power factor.

X_{d1} = Cylindrical-rotor machine (over-excited).

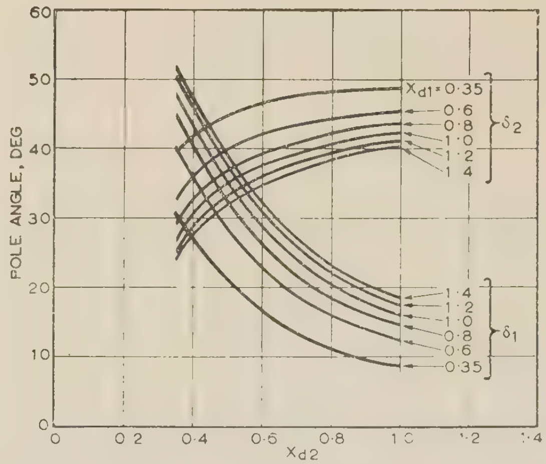

Fig. 21.—Pole angles at pull-out for cylindrical-rotor and salient-pole machines ($X_d/X_q = 1 \cdot 6$) at 0·5 power factor.

X_{d1} = Cylindrical-rotor machine (over-excited).

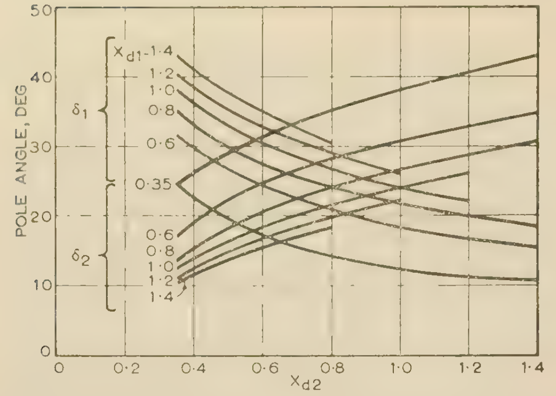

Fig. 22.—Pole angles at pull-out for two salient-pole machines both with $X_d/X_q = 2 \cdot 5$ at unity power factor.

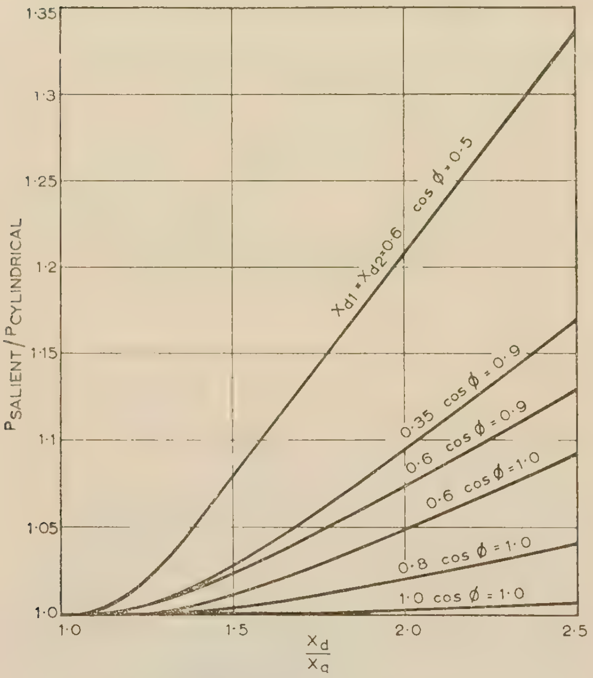

Fig. 23.—Variation of pull-out power with saliency.

cerning voltage, current, power factor and pole angle are given only for the more common cases of Table 1 and are shown in Figs. 5–22.

In order to illustrate the effect of saliency Fig. 23 has been prepared. Various pairs of combinations have been arbitrarily selected and a calculation has been made of the ratio between the pull-out power with a given degree of saliency, i.e. a given value of X_d/X_q, and that with two cylindrical-rotor machines having the same synchronous reactances, X_d, and power factors. This ratio has been plotted against saliency, X_d/X_q, as shown.

When two synchronous machines are operating in parallel the pull-out power of the combination is very much less than that of either machine when operating in parallel with an infinite grid. This point is illustrated for case 3(d) of Table 1 in Fig. 24, which shows the ratio between the pull-out power of the combination and that of each machine when running in parallel with an infinite grid.

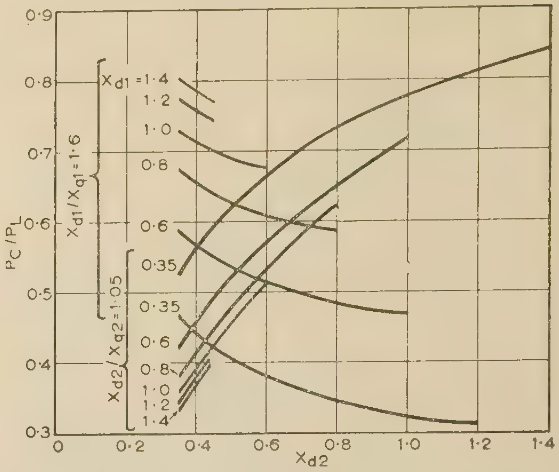

Fig. 24.—Pull-out power for two salient-pole machines expressed as a ratio to the pull-out power of each machine on an infinite busbar at unity power factor.

$X_{d1}/X_{q1} = 1 \cdot 6.$
$X_{d2}/X_{q2} = 1 \cdot 05.$

(5.1) Use of Curves and Tables

(5.1.1) General Case.

The use of Table 4 may be illustrated by the following example.* A number of 6 MW turbo-alternators running in parallel are supplying a lighting and industrial load, the latter including a salient-pole synchronous motor rated at 6 MW 0·9 power-factor over-excited. If the motor under these conditions is assumed to be connected to an infinite grid, with a synchronous reactance of 0·6 p.u. and $X_d/X_q = 1 \cdot 6$, its pull-out power will be 2·75 p.u. During the night most or all of the load is switched out, so that with the motor running on a 24-hour basis it is possible to shut down all but one of the alternators.

The one alternator will then be running at 0·9 power factor (under-excited). Assuming that the alternator impedance is 0·8 and $X_d/X_q = 1 \cdot 05$, the pull-out torque of the combination may be obtained from either (u) or (v) of Table 4.

Since the alternator is the under-excited machine, Fig. 4 [(u) of Table 4] is used and $X_{d2} = 0 \cdot 8$, $X_{d1} = 0 \cdot 6$. The intersection of the ordinate at $X_{d2} = 0 \cdot 8$ with the curve $X_{d1} = 0 \cdot 6$ gives the required pull-out power = 0·944 p.u. In the per-unit system this pull-out power is the ratio of the pull-out power in kilowatts to the rated power in kilovolt-amperes, so that the true pull-out power, expressed as a ratio of the rated power in kilowatts of the machine, is given by $\dfrac{\text{Pull-out power (kW)}}{\text{Rated power factor}}$; in this case 0·944/0·9 = 1·05, i.e. only 38% of the design figure.

If the operating conditions are changed, so that the synchronous motor runs under-excited and the generator over-excited, (v) of Table 4 is used. In this case, the intersection of the ordinate at $X_{d2} = 0 \cdot 6$ with the curve $X_{d1} = 0 \cdot 8$ gives the required pull-out power = 1·016/0·9 = 1·128. By this change in excitation the pull-out margin is increased $2\frac{1}{2}$ times, and provided that the increase in field current in the alternator causes no difficulties relative to the heating of the rotor winding, this change is obviously advantageous.

The above example assumes that, relatively, the alternator is the high-reactance and the motor the low-reactance machine. If these conditions are changed so that the alternator reactance is 0·6 and the motor reactance 0·8, the above results relative to excitation are reversed, as can be seen from the following:

As before, with the motor over-excited, Fig. 4 is used, but

* If frequent reference to Table 4 is required it is advisable to plot families of curves from the given values.

here the pull-out is given by the intersection of the ordinate at $X_{d2} = 0{\cdot}6$ with the curve $X_{d1} = 0{\cdot}8$. This gives a pull-out power of $0{\cdot}992/0{\cdot}9 = 1{\cdot}102$. Changing over the field conditions so that the motor is under-excited, the pull-out power from (*v*) of Table 4 is now $0{\cdot}969/0{\cdot}9 = 1{\cdot}077$, which reduces the pull-out margin by a quarter.

With a designed pull-out torque of 2·75 p.u. it is obvious that satisfactory operation of the synchronous motor would not be possible. If the motor is driving a steel mill, the actual pull-out required may be and probably is, in most cases, substantially lower than the design figure, e.g. 20% lower. In this case a sufficient number of generators would have to be kept on the busbars to ensure that the minimum figure of pull-out was obtained. By extrapolation from Fig. 4 it is found that, for a pull-out power of $(0{\cdot}9 \times 2{\cdot}75)/1{\cdot}25 = 1{\cdot}98$, the combined alternator reactance should be about 0·04; i.e. about 20 $(= 0{\cdot}8/0{\cdot}04)$ 6 MW sets would have to be run in parallel to satisfy the above conditions.

Table 2

Typical Pull-Out Values for a Ship-Propulsion Equipment

Case number	Type of machine	X_d	Power factor and excitation	I_f	Values at pull-out point				Values at pull-out point for two cylindrical-rotor machines			
					Pull-out power	I	V	Power factor	Pull-out power	I	V	Power factor
1	C.R. S.P.	0·8 0·6	1·0 1·0	1·28 1·17	1·07	1·24	0·87	1·00	1·07	1·24	0·87	1·00
2	C.R. S.P.	0·8 0·6	0·9 under 0·9 over	0·97 1·37	1·05	1·20	0·89	0·89	1·06	1·20	0·89	0·90
3	C.R. S.P.	0·8 0·6	0·9 over 0·9 under	1·53 0·92	1·13	1·29	0·83	0·94	1·11	1·28	0·84	0·94
4	C.R. S.P.	0·8 0·6	0·5 under 0·5 over	0·50 1·55	1·12	1·17	0·91	0·53	1·12	1·17	0·91	0·53
5	C.R. S.P.	0·8 0·6	0·5 over 0·5 under	1·74 0·57	1·54	1·36	0·79	0·72	1·41	1·31	0·81	0·66
6	C.R. S.P.	0·6 0·6	1·0 1·0	1·17 1·17	1·14	1·39	0·81	1·00	1·14	1·38	0·81	1·00

C.R. = Cylindrical-rotor machine.
S.P. = Salient-pole machine.

Table 3

Pole Angles Corresponding to the Case Numbers in Table 2

Case number	Type of machine	X_d	Pole angle (full load) δ	Pole angle (pull-out) δ'	$\delta' - \delta$	Type of machine	X_d	Pole angle (full load) δ	Pole angle (pull-out) δ'	$\delta' - \delta$
			deg	deg	deg			deg	deg	deg
1	C.R. S.P.	0·8 0·6	38·6 20·6 Sum 59·2	50·9 27·6 78·5	19·3	C.R. C.R.	0·8 0·6	38·6 31·0 Sum 69·6	50·5 39·4 89·9	20·3
2	C.R. S.P.	0·8 0·6	47·9 18·7 Sum 66·6	61·8 20·3 82·1	15·5	C.R. C.R.	0·8 0·6	47·9 23·1 Sum 71·0	61·8 27·7 89·5	18·5
3	C.R. S.P.	0·8 0·6	28·1 28·3 Sum 56·4	39·4 34·2 73·6	17·2	C.R. C.R.	0·8 0·6	28·1 36·2 Sum 64·3	38·6 51·4 90·0	25·7
4	C.R. S.P.	0·8 0·6	52·4 8·1 Sum 60·5	76·2 10·2 86·4	25·9	C.R. C.R.	0·8 0·6	52·4 11·2 Sum 63·6	76·2 13·6 89·8	26·2
5	C.R. S.P.	0·8 0·6	13·3 15·5 Sum 28·8	26·4 39·4 65·8	37·0	C.R. C.R.	0·8 0·6	13·3 32·0 Sum 45·3	23·4 66·3 89·7	44·4
6	C.R. S.P.	0·6 0·6	31·0 20·6 Sum 51·6	45·6 32·3 77·9	26·3	C.R. C.R.	0·6 0·6	31·0 31·0 Sum 62·0	45·0 45·0 90·0	28·0

C.R. = Cylindrical-rotor machine.
S.P. = Salient-pole machine.

Table 4

PULL-OUT POWER PER UNIT FOR TWO SYNCHRONOUS MACHINES

Conditions	Power factor	X_{d2}	X_{d1}					
			0·35	0·6	0·8	1·0	1·2	1·4
(*a*) Two cylindrical-rotor machines	1·0	0·35	1·6	1·303	1·18	1·11	1·063	1·042
		0·6	1·305	1·135	1·07	1·032	1·012	1·002
		0·8	1·18	1·067	1·026	1·008	—	—
		1·0	1·109	1·033	1·007	1·0	—	—
		1·2	1·069	1·012	1·0	—	—	—
		1·4	1·04	1·001	—	—	—	—
(*b*) Two cylindrical-rotor machines. X_{d1} refers to the over-excited machine	0·9	0·35	1·545	1·309	1·203	1·14	1·091	1·057
		0·6	1·153	1·05	1·0	0·971	0·952	0·934
		0·8	1·01	0·951	0·926	0·915	0·908	0·901
		1·0	0·94	0·912	0·902	—	—	—
		1·2	0·911	0·901	—	—	—	—
		1·4	—	—	—	—	—	—
(*c*) Two cylindrical-rotor machines. X_{d1} refers to the over-excited machine	0·5	0·35	1·35	1·172	1·09	1·028	0·985	0·956
		0·6	0·788	0·735	0·706	0·688	0·67	0·66
		0·8	0·577	0·558	0·548	0·54	0·535	0·528
		1·0	0·505	0·501	—	—	—	—
		1·2	—	—	—	—	—	—
		1·4	—	—	—	—	—	—
(*d*) Cylindrical-rotor and salient-pole machine. $X_{d2}/X_{q2} = 1·6$. X_{d1} refers to the cylindrical-rotor machine	1·0	0·35	1·633	1·309	1·185	1·112	1·068	1·042
		0·6	1·328	1·142	1·072	1·034	1·015	1·003
		0·8	1·201	1·074	1·028	1·01	1·001	—
		1·0	1·125	1·037	1·008	1·0	—	—
		1·2	1·08	1·015	1·0	—	—	—
		1·4	1·047	1·004	—	—	—	—
(*e*) Cylindrical-rotor and salient-pole machine. $X_{d2}/X_{q2} = 1·6$. X_{d1} refers to the cylindrical-rotor machine (under-excited)	0·9	0·35	1·557	1·16	1·01	0·95	0·91	—
		0·6	1·325	1·051	0·945	0·911	0·903	—
		0·8	1·216	1·003	0·925	0·905	—	—
		1·0	1·149	0·97	0·915	0·901	—	—
		1·2	1·1	0·95	0·906	—	—	—
		1·4	1·06	0·931	—	—	—	—
(*f*) Cylindrical-rotor and salient-pole machine. $X_{d2}/X_{q2} = 1·6$. X_{d1} refers to the cylindrical-rotor machine (over-excited)	0·9	0·35	1·59	1·332	1·196	1·126	1·099	1·062
		0·6	1·2	1·072	1·018	0·98	0·959	0·943
		0·8	1·04	0·971	0·94	0·921	0·911	0·905
		1·0	0·958	0·919	0·907	0·901	—	—
		1·2	0·918	0·901	—	—	—	—
		1·4	0·903	—	—	—	—	—
(*g*) Cylindrical-rotor and salient-pole machine. $X_{d2}/X_{q2} = 1·6$. X_{d1} refers to the cylindrical-rotor machine (under-excited)	0·5	0·35	1·36	0·786	0·576	0·504	—	—
		0·6	1·184	0·732	0·56	—	—	—
		0·8	1·096	0·705	0·55	—	—	—
		1·0	1·036	0·687	0·542	—	—	—
		1·2	0·993	0·672	0·536	—	—	—
		1·4	0·956	0·66	0·531	—	—	—
(*h*) Cylindrical-rotor and salient-pole machine. $X_{d2}/X_{q2} = 1·6$. X_{d1} refers to the cylindrical-rotor machine (over-excited)	0·5	0·35	1·44	1·224	1·126	1·059	1·014	0·981
		0·6	0·9	0·813	0·768	0·74	0·72	0·702
		0·8	0·668	0·629	0·607	0·593	0·585	0·575
		1·0	0·545	0·529	0·52	0·515	0·511	0·508
		1·2	—	—	—	—	—	—
(*j*) Two salient-pole machines both with $X_d/X_q = 1·05$	1·0	0·35	1·605	1·3	1·178	1·108	1·067	1·041
		0·6	1·302	1·132	1·065	1·03	1·011	1·004
		0·8	1·178	1·067	1·024	1·008	—	—
		1·0	1·107	1·03	1·006	—	—	—
		1·2	1·066	1·011	—	—	—	—
		1·4	1·04	1·002	—	—	—	—
(*k*) Two salient-pole machines both with $X_d/X_q = 1·05$. X_{d1} refers to the over-excited machine	0·9	0·35	1·545	1·305	1·2	1·135	1·089	1·056
		0·6	1·152	1·047	0·999	0·97	0·95	0·936
		0·8	1·009	0·952	0·928	0·916	0·906	0·901
		1·0	0·94	0·912	0·901	—	—	—
		1·2	0·91	—	—	—	—	—
		1·4	0·9	—	—	—	—	—
(*l*) Two salient-pole machines both with $X_d/X_q = 1·05$. X_{d1} refers to the over-excited machine	0·5	0·35	1·35	1·165	1·085	1·03	0·985	0·953
		0·6	0·785	0·73	0·703	0·685	0·67	0·656
		0·8	0·577	0·558	0·548	0·541	0·535	0·531
		1·0	0·501	—	—	—	—	—
		1·2	—	—	—	—	—	—

Table 4—*continued*

Conditions	Power factor	X_{d2}	X_{d1} 0·35	0·6	0·8	1·0	1·2	1·4
(*m*) Two salient-pole machines both with $X_d/X_q = 1·6$	1·0	0·35	1·625	1·285	1·158	1·084	1·041	1·013
		0·6	1·347	1·125	1·05	1·008	—	—
		0·8	1·197	1·057	1·008	—	—	—
		1·0	1·119	1·02	—	—	—	—
		1·2	1·071	—	—	—	—	—
		1·4	1·038	—	—	—	—	—
(*n*) Two salient-pole machines both with $X_d/X_q = 1·6$. X_{d1} refers to the over-excited machine	0·9	0·35	1·595	1·322	1·21	1·135	1·095	1·051
		0·6	1·203	1·067	1·011	0·975	0·951	0·934
		0·8	1·045	0·965	0·936	0·918	0·908	—
		1·0	0·96	0·915	0·901	—	—	—
		1·2	0·92	—	—	—	—	—
		1·4	0·902	—	—	—	—	—
(*p*) Two salient-pole machines both with $X_d/X_q = 1·6$. X_{d1} refers to the over-excited machine	0·5	0·35	1·45	1·23	1·13	1·065	1·013	0·979
		0·6	0·9	0·817	0·773	0·744	0·723	0·703
		0·8	0·658	0·625	0·605	0·591	0·579	0·572
		1·0	0·528	0·52	0·51	0·507	0·503	0·502
		1·2	—	—	—	—	—	—
		1·4	—	—	—	—	—	—
(*q*) Two salient-pole machines both with $X_d/X_q = 2·5$	1·0	0·35	1·84	1·46	1·3	1·202	1·136	1·09
		0·6	1·46	1·23	1·131	1·075	1·042	1·019
		0·8	1·3	1·13	1·065	1·03	1·012	1·002
		1·0	1·204	1·075	1·031	1·009	1·0	—
		1·2	1·136	1·041	1·014	1·0	—	—
		1·4	1·09	1·02	1·002	—	—	—
(*r*) Two salient-pole machines both with $X_d/X_q = 2·5$. X_{d1} refers to the over-excited machine	0·9	0·35	1·8	1·47	1·35	1·233	1·168	1·12
		0·6	1·36	1·17	1·092	1·037	1·0	0·975
		0·8	1·165	1·036	0·979	0·943	0·917	0·903
		1·0	1·047	0·965	0·929	0·908	—	—
		1·2	0·975	0·926	0·905	—	—	—
		1·4	0·935	0·905	—	—	—	—
(*s*) Two salient-pole machines both with $X_d/X_q = 2·5$. X_{d1} refers to the over-excited machine	0·5	0·35	1·67	1·362	1·226	1·134	1·07	1·024
		0·6	1·11	0·974	0·905	0·856	0·822	0·794
		0·8	0·81	0·745	0·71	0·682	0·662	0·643
		1·0	0·6	0·57	0·555	0·546	0·536	0·525
		1·2	—	—	—	—	—	—
(*t*) Two salient-pole machines. $X_{d1}/X_{q1} = 1·6$. $X_{d2}/X_{q2} = 1·05$	1·0	0·35	1·59	1·277	1·155	1·082	1·04	1·012
		0·6	1·297	1·115	1·045	1·003	—	—
		0·8	1·172	1·05	1·003	—	—	—
		1·0	1·1	1·013	—	—	—	—
		1·2	1·059	—	—	—	—	—
		1·4	1·032	—	—	—	—	—
(*u*) Two salient-pole machines. See Fig. 4. $X_{d1}/X_{q1} = 1·6$ (over-excited). $X_{d2}/X_{q2} = 1·05$ (under-excited)	0·9	0·35	1·539	1·298	1·19	1·122	1·076	1·045
		0·6	1·15	1·036	0·991	0·96	0·94	0·925
		0·8	1·003	0·943	0·92	0·908	—	—
		1·0	0·936	0·903	—	—	—	—
		1·2	0·907	—	—	—	—	—
(*v*) Two salient-pole machines. $X_{d1}/X_{q1} = 1·05$ (over-excited). $X_{d2}/X_{q2} = 1·6$ (under-excited)	0·9	0·35	1·6	1·330	1·217	1·145	1·097	1·061
		0·6	1·2	1·073	1·015	0·981	0·958	0·943
		0·8	1·043	0·968	0·939	0·922	0·912	0·904
		1·0	0·96	0·921	0·905	—	—	—
		1·2	0·919	0·901	—	—	—	—
		1·4	0·902	—	—	—	—	—
(*w*) Two salient-pole machines. $X_{d1}/X_{q1} = 1·6$ (over-excited). $X_{d2}/X_{q2} = 1·05$ (under-excited)	0·5	0·35	1·35	1·165	1·085	1·025	0·98	0·95
		0·6	0·785	0·725	0·7	0·684	0·665	0·652
		0·8	0·574	0·558	0·548	0·54	0·532	0·525
		1·0	0·501	—	—	—	—	—
(*x*) Two salient-pole machines. $X_{d1}/X_{q1} = 1·05$ (over-excited). $X_{d2}/X_{q2} = 1·6$ (under-excited)	0·5	0·35	1·45	1·225	1·13	1·062	1·03	0·975
		0·6	0·893	0·803	0·765	0·74	0·716	0·7
		0·8	0·653	0·618	0·597	0·584	0·574	0·565
		1·0	0·524	0·515	0·505	0·5	—	—

Pull-out power must be divided by rated power factor to give pull-out power in p.u. kilowatts. Dashes denote unstable conditions.

(5.1.2) **Electric Ship Propulsion.**

(5.1.2.1) *Turbo-Electric Drive.*

A common arrangement in the electric propulsion of ships is to have one high-speed turbo-alternator supplying one low-speed double-unit salient-pole synchronous motor directly connected to a propeller shaft.[5] The number of such combinations of generator and motor is usually, but not invariably, governed by the number of propellers.

To illustrate the use of the data in the present paper an example is investigated in which a cylindrical-rotor alternator supplies a salient-pole synchronous motor; the pull-out power is required to be 10% greater than the normal operating power. In general, field heating is more likely to be a limitation to output in the cylindrical-rotor than in the salient-pole machine, and for this reason a preliminary assumption is made that the alternator reactance is 0·8 p.u. and the motor reactance 0·6 p.u.

As is well known, the pull-out power for a given kilowatt rating at unity power factor of a synchronous machine, running in parallel with an infinite busbar, is increased by operation at a lower power factor. In the two-machine problem considered here, at power factors other than unity one machine operates at a lagging power-factor (over-excited) and the other at a leading (under-excited), so that it is necessary to consider in detail the effect of power-factor on the pull-out power.

The alternator is assumed to have no saliency effect ($X_d/X_q = 1$), the synchronous motor a saliency corresponding to $X_d/X_q = 1{\cdot}6$. The problem of the determination of the characteristics of this combination thus corresponds to cases 2 of Table 1. All the relevant numerical data for the various combinations of 1·0, 0·9 and 0·5 power factor are shown in Tables 2 and 3, cases 1–5.

To explain the construction of these two Tables, the derivation of cases 2 in Tables 2 and 3 will be given in detail.

Referring now to cases 2 of Table 2, the alternator is running at 0·9 power factor (under-excited) and the motor at 0·9 power factor (over-excited). The field current at rated load and power factor is calculated in both cases from the equations given in Reference 1.

From (*e*) of Table 4 the pull-out power is read off for $X_{d2} = 0{\cdot}6$ with $X_{d1} = 0{\cdot}8$, i.e. $0{\cdot}945/0{\cdot}9 = 1{\cdot}05$, as shown. Referring now to Fig. 9, the intersection of the ordinate at $X_{d2} = 0{\cdot}6$ with the pull-out voltage curve $X_{d1} = 0{\cdot}8$ gives pull-out voltage = 0·89 volt; with the pull-out current curve $X_{d1} = 0{\cdot}8$ gives pull-out current = 1·2 amp; and with the power-factor curve $X_{d1} = 0{\cdot}8$ gives the pull-out power factor 0·89. The load pole angles are obtained from Reference 1, and the corresponding values at pull-out can be read off from Fig. 18.

It can be seen from Table 2 that with the given synchronous reactances the required pull-out power of 1·1 p.u. cannot be obtained at 1·0 or 0·9 power factor with the alternator under-excited and the motor over-excited. It can, however, be obtained at 0·9 power factor with the alternator over-excited and the motor under-excited and for all conditions at 0·5 power factor, cases 4 and 5 of Table 2. For normal conditions, operation at 0·5 power factor would be completely uneconomic, since, for a given power, the apparent power at 0·5 power factor would be rather more than double that at unity power factor.

It will also be realized that any deviation from unity power factor will in general increase the cost and reduce the efficiency of the combination. Against this should be set the fact that a decrease in the synchronous reactance will also be accompanied by an increase in cost and reduction in efficiency of the combination. This at once raises the question whether a more economical combination might not be obtained by reducing the synchronous reactance of one of the machines in the unity power factor case, in order to increase the pull-out power. The results of such a change are shown in case 6, Tables 2 and 3, in which the alternator reactance is reduced to 0·6 p.u., the motor reactance remaining unchanged. It can be seen that this combination gives the required pull-out power; the final decision as to whether case 3 or case 6 gives the more economical or more efficient installation can only be made after an investigation of the design and cost.

The pole angles on full load and at pull-out given in Table 3 can assume some importance in those cases where the voltage regulator is of a type which is actuated, in part, by variations in the pole angle of the machines being controlled.

(5.1.2.2) *Diesel-Electric Ship Propulsion.*

For Diesel-electric ship propulsion the characteristics of this combination would be determined in the same manner as for the turbo-electric drive; the main differences arise from the condition that the Diesel engine, being a relatively low-speed unit, would be coupled to a salient-pole alternator. The use of the latter type of generator would, in general, permit the synchronous reactance of this machine to be lower than that of the cylindrical-rotor turbo-alternator.

(6) EFFECT OF SALIENCY

It has been shown elsewhere[1,2] that a salient-pole machine running in parallel with an infinite busbar has, in many respects, better operating characteristics than a cylindrical-rotor machine. The main advantage is that in the under-excited region it enables a machine to operate stably at a higher apparent power with saliency than without.

The measure of saliency is, of course, X_d/X_q, which may vary from 1·4 to 2·5 in normal salient-pole machines and from 1·0 to 1·05 in cylindrical-rotor machines.

In the two-machine case, the main interest in saliency is its effect on the pull-out power for various rated power factors and combinations of synchronous reactances. Since Table 4 gives pull-out powers for varying degrees of saliency, it is possible to prepare Fig. 23 from this information.

It can be seen that for $X_d/X_q = 1{\cdot}6$, which is normal for salient-pole machines, the increased pull-out obtained from saliency is of little significance in the two-machine problem if, as will usually be the case, the rated power factor is 0·9 or higher. When, however, for any reason, such as the reduction of the ratio between pole-arc and pole-pitch in 4-pole salient-pole machines from 70% to 60%, the value of X_d/X_q is increased towards 2·5, then, even at 0·9 power-factor the increased pull-out power is significant, amounting to 12–15%.

(7) PULL-OUT POWER ON AN INFINITE BUSBAR

The pull-out power of a synchronous machine is much greater when connected to an infinite busbar than when running in parallel with another machine, and is largely due to the reduction in terminal voltage as the load between the two machines is increased beyond the rated value. In order to illustrate this point, a comparison has been made between the pull-out powers of a salient-pole machine ($X_d/X_q = 1{\cdot}6$) and a turbo-alternator ($X_d/X_q = 1{\cdot}05$) on an infinite grid and the pull-out power of the combination. This comparison is shown in Fig. 24, in which the pull-out power of each machine on an infinite grid has been calculated from the equations in Reference 1.

(8) CONCLUSIONS

The paper gives a solution to the problems of determining the operating characteristics of two synchronous machines running in parallel. The solution can be applied to determine the extent

to which a large synchronous machine connected to a supply may be considered as running on an infinite busbar.

The paper shows how, in designing a ship-propulsion installation, a preliminary investigation may be carried out to determine the optimum value of power factor, ratio of reactances and field excitations of the two machines.

It also shows that at high power factors the saliency of one or both machines has little or no effect on the pull-out power, whilst at low power factors the effect of saliency is pronounced.

Finally, it is shown that the pull-out power of two machines in parallel is much less than that of either machine operating on an infinite busbar.

(9) ACKNOWLEDGMENTS

The authors are indebted to the Directors of the British Thomson-Houston Co., Ltd., for permission to publish the paper. They also wish to acknowledge the invaluable assistance they received from their former colleague, Mrs. M. J. Baynton, who carried out the difficult and tedious computational work required in the production of the curves and numerical data given in the paper.

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(11) APPENDIX

(11.1) Equations for Two Cylindrical-Rotor Machines

(11.1.1) Pull-out Condition of two Identical Cylindrical-Rotor Machines at Unity Power Factor.

In Fig. 1, because the machines are identical and at unity power factor,

$$\delta_1 = \delta_2; \quad V_{01} = V_{02}; \quad X_{d1} = X_{d2}; \quad \phi = 0$$

$$\text{Power} = VI = \frac{\text{Area Oab}}{X_{d1}}$$

The area of the triangle Oab is also $\frac{1}{2}V_{01}^2 \sin 2\delta_1$.

Therefore, $$\text{Power} = \frac{V_{01}^2 \sin 2\delta_1}{2X_{d1}}$$

which is a maximum when $2\delta_1 = 90°$, i.e. $\delta_1 = 45°$.

Pull-out power is therefore $V_{01}^2/2X_{d1}$.
Terminal voltage at pull-out is $V_{01}/\sqrt{2}$.
Current at pull-out is $V_{01}/X_{d1}\sqrt{2}$.

(11.1.2) Pull-out Condition of Two Dissimilar Cylindrical-Rotor Machines.

Again, using Fig. 1,

$$\text{Power} = VI\cos\phi = \frac{2\,(\text{Area Oab})}{X_{d1} + X_{d2}}$$

$$\text{Area Oab} = \frac{V_{01}V_{02}\sin(\delta_1 + \delta_2)}{2}$$

Therefore the power is a maximum when $\delta_1 + \delta_2 = 90°$ and the pull-out power is

$$P' = \frac{V_{01}V_{02}}{X_{d1} + X_{d2}}$$

This position in the vector diagram is denoted by δ_1' and δ_2'.

By considering the triangle Oa′b′ it is not difficult to show that the pull-out angles are given by

$$\tan\delta_1' = \frac{V_{02}X_{d1}}{V_{01}X_{d2}} \qquad \tan\delta_2' = \frac{V_{01}X_{d2}}{V_{02}X_{d1}}$$

Current at pull-out is given by

$$I' = \frac{\sqrt{(V_{01}^2 + V_{02}^2)}}{X_{d1} + X_{d2}}$$

Terminal voltage at pull-out is given by

$$V' = \frac{\sqrt{(V_{01}^2X_{d2}^2 + V_{02}^2X_{d1}^2)}}{X_{d1} + X_{d2}}$$

The power factor at pull-out may also be obtained if required by using the relation $P' = V'I'\cos\phi'$.

(11.2) Equations for Cylindrical-Rotor and Salient-Pole Machines

(11.2.1) Pull-out Condition of a Cylindrical-Rotor and a Salient-Pole Machine.

In Fig. 2, qb $= V_{02}$, cb $= IX_{d2}$, ca $= IX_{d1}$, Oa $= V_{01}$, Oc $= V$, Op $= \gamma V$.

By considering the projections of cb and ca on Oc and a line through c perpendicular to Oc, it may be seen that

$$\frac{X_{d2}}{X_{d1}} = \frac{(V_{02} + \gamma V\cos\delta_2)\sin\delta_2}{V_{01}\sin\delta_1} \quad . \quad . \quad . \quad (1)$$

$$\frac{X_{d2}}{X_{d1}} = \frac{(V_{02} + \gamma V\cos\delta_2)\cos\delta_2 - (1+\gamma)V}{V - V_{01}\cos\delta_1} \quad . \quad . \quad (2)$$

Eliminating δ_1 from eqns. (1) and (2),

$$X_{d2}^2V_{01}^2 = [X_{d1}V_{02} - V(X_{d1} + X_{d2})\cos\delta_2]^2 + V^2\sin^2\delta_2(X_{d2} + X_{d1} + \gamma X_{d1})^2 \quad . \quad (3)$$

Let $y = V\sin\delta_2(X_{d2} + X_{d1} + \gamma X_{d1})$

and $$z = -X_{d1}V_{02} + V(X_{d1} + X_{d2})\cos\delta_2$$

Eqn. (3) then becomes

$$X_{d2}^2V_{01}^2 = y^2 + z^2 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The power $P = VI\cos\phi = \dfrac{2\Delta obc}{X_{d2}}$

$$= \frac{V(V_{02} + \gamma V\cos\delta_2)\sin\delta_2}{X_{d2}}$$

Therefore $$P = \frac{y(cV_{02} + \gamma z)}{c(X_{d1} + X_{d2})X_{d2}}$$

where $$c = X_{d2} + X_{d1} + \gamma X_{d1}$$

The pull-out condition is determined by finding the maximum value of P as a function of y and z subject to eqn. (4) being satisfied. After some manipulation this gives

$$z = \frac{-cV_{02} + \sqrt{(c^2V_{02}^2 + 8\gamma^2X_{d2}^2V_{01}^2)}}{4\gamma}$$

and hence the pull-out power

$$P' = \frac{(V_{02} + \gamma z/c)\sqrt{(X_{d2}^2V_{01}^2 - z^2)}}{X_{d2}(X_{d1} + X_{d2})}$$

The pull-out angles are given by

$$\tan \delta_2' = \frac{(X_{d2} + X_{d1})\sqrt{(X_{d2}^2V_{01}^2 - z^2)}}{c(z + X_{d1}V_{02})}$$

$$\sin \delta_1' = \frac{X_{d1}\sin\delta_2'(cV_{02} + \gamma z)}{X_{d2}V_{01}(X_{d2} + X_{d1})}$$

and the terminal voltage at pull-out is

$$V' = \left[\left(\frac{X_{d1}V_{02} + z}{X_{d2} + X_{d1}}\right)^2 + \frac{X_{d2}^2V_{01}^2 - z^2}{c^2}\right]^{1/2}$$

If the current at pull-out is required it can easily be obtained from the vector diagram (Fig. 2) since V' and δ_1' can be evaluated from the above formulae: and then

$$I'^2X_{d1}^2 = V'^2 + V_{01}^2 - 2V'V_{01}\cos\delta_1'$$

The power factor may be obtained from $P' = V'I'\cos\phi'$.

(11.3) Equations for Two Salient-Pole Machines

(11.3.1) Pull-out Condition of Two Identical Salient-Pole Machines at Unity Power Factor.

The vector diagram for this condition is as shown in Fig. 3, with $\phi = 0$, $\delta_1 = \delta_2$, $V_{01} = V_{02}$, $X_{d1} = X_{d2}$, the large pair of circles coinciding with the smaller pair, and the whole diagram symmetrical about cOp.

Since Oc $= V$ and Op $= \gamma V$, cp $= V(1 + \gamma) = VX_{d2}/X_{q2}$.

Therefore $$IX_{d2} = \frac{VX_{d2}}{X_{q2}}\tan\delta_2$$

Hence $$IX_{q2} = V\tan\delta_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Also, since cp $=$ bp $\cos\delta_2$ when $\phi = 0$, we have

$$\frac{VX_{d2}}{X_{q2}} = \left[V_{02} + V\left(\frac{X_{d2}}{X_{q2}} - 1\right)\cos\delta_2\right]\cos\delta_2 \quad . \quad (6)$$

Now the power is given by

$$P = VI = \frac{V^2\tan\delta_2}{X_{q2}}$$

and, substituting for V from eqn. (6), we have after some reduction

$$P = \frac{V_{02}^2\cos\delta_2\sin\delta_2}{X_{q2}[\alpha - (\alpha - 1)\cos^2\delta_2]^2} \quad . \quad . \quad . \quad (7)$$

where $\alpha = X_{d2}/X_{q2}$.

The pull-out condition is given by finding the maximum value of P. Using eqn. (7) and the condition $dP/d\delta_2 = 0$ at pull-out, it is again found after some simplification that the pull-out angle is given by

$$\cos^2\delta_2' = \frac{2\alpha}{(3 - \alpha) + \sqrt{(9\alpha^2 - 14\alpha + 9)}}$$

Having found δ_2' the pull-out power is obtained from

$$P' = \frac{V_{02}^2\cos\delta_2'\sin\delta_2'}{X_{q2}[\alpha - (\alpha - 1)\cos^2\delta_2']^2}$$

The terminal voltage is given by

$$V' = \frac{V_{02}\cos\delta_2'}{\alpha - (\alpha - 1)\cos^2\delta_2'}$$

and the current by $$I' = \frac{V'\tan\delta_2'}{X_{q2}}$$

(11.3.2) Pull-out Condition of Two Dissimilar Salient-Pole Machines.

The vector diagram is given in Fig. 3, where

cb $= IX_{d2}$; ca $= IX_{d1}$; Oc $= V$; qb $= V_{02}$; ra $= V_{01}$

By considering the projections of cb and ca on Oc and on a line through c perpendicular to Oc, it follows that

$$X_{d1}(V_{02} + \gamma V\cos\delta_2)\sin\delta_2 = X_{d2}(V_{01} + \beta V\cos\delta_1)\sin\delta_1 \quad . \quad (8)$$

$$X_{d1}(V_{02} + \gamma V\cos\delta_2)\cos\delta_2 = -X_{d2}(V_{01} + \beta V\cos\delta_1)\cos\delta_1 + Vc \quad . \quad (9)$$

where $\beta = X_{d1}/X_{q1} - 1$, $\gamma = X_{d2}/X_{q2} - 1$,

and $c = V[X_{d1}(1 + \gamma) + X_{d2}(1 + \beta)]$

In order to find an equation for power involving V and δ_1, but not δ_2, we eliminate δ_2 from eqns. (8) and (9).

$$\begin{aligned} X_{d1}V_{02}[c^2y^2 &+ x^2(c^2 + X_{d2}^2\beta^2 - 2X_{d2}c\beta) + x(2X_{d2}^2V_{01}\beta \\ &- 2X_{d2}cV_{01}) + X_{d2}^2V_{01}^2]^{1/2} = (c^2 - X_{d1}c\gamma)y^2 \\ &+ x^2(c^2 + X_{d2}^2\beta^2 - 2X_{d2}c\beta - X_{d1}c\gamma + X_{d1}X_{d2}\gamma\beta) \\ &+ x(2X_{d2}^2V_{01}\beta - 2X_{d2}cV_{01} + X_{d1}X_{d2}\gamma V_{01}) + X_{d2}^2V_{01}^2 \end{aligned} \quad . \quad . \quad . \quad . \quad (10)$$

where $y = V\sin\delta_1$ and $x = V\cos\delta_1$.

Power $$P = \frac{V\sin\delta_1(V_{01} + \beta V\cos\delta_1)}{X_{d1}}$$

as shown in Section 11.2.1.

Therefore $$P = \frac{y(V_{01} + \beta x)}{X_{d1}} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The pull-out condition is determined by making P a maximum subject to eqn. (10) being satisfied. This may be done in the following way:

Dividing eqn. (10) by $x_{d1}V_{02}c$, we obtain

$$\sqrt{(y^2 + fx^2 + gx + h)} = ky^2 + Fx^2 + Gx + H$$

where the coefficients are obtained from the coefficients in eqn. (10), e.g.

$$k = \frac{c^2 - cX_{d1}\gamma}{X_{d1}cV_{02}}$$

Now let $$z = \sqrt{(y^2 + fx^2 + gx + h)}$$

and we have $z = kz^2 +$ a quadratic in x, i.e.

$$z^2 + lz + Q_1(x) = 0 \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where $Q_1(x)$ is a quadratic in x and $l = -1/k$.

We require $y(V_{01} + \beta x)/X_{d1}$ to be a maximum, i.e. $\imath + nx)^2(z^2 - fx^2 - gx - h)$ to be a maximum, subject to n. (12) being satisfied, where $m = V_{01}/X_{d1}$ and $n = \beta/X_{d1}$.

Using the method of undetermined multipliers, we have

$$(m + nx)^2 2z + \lambda(2z + l) = 0$$

$$\imath(m + nx)z^2 - 2n(m + nx)(fx^2 + gx + h) - (m + nx)^2(2fx + g) + \lambda Q_1'(x) = 0$$

Hence, eliminating λ,

$$z^3 + \tfrac{1}{2}lz^2 + zQ_2 + Q_3 = 0 \quad . \quad . \quad . \quad . \quad (13)$$

here Q_2 and Q_3 are quadratics in x.

From eqns. (12) and (13) we obtain

$$z^2 + \frac{2z}{l}[Q_1(x) - Q_2(x)] - \frac{2Q_3(x)}{l} = 0 \quad . \quad . \quad (14)$$

nd, eliminating z from eqns. (12) and (14),

$$Q_1(x) + \frac{2}{l}Q_3(x)\Big]^2 - \Big\{l - \frac{2}{l}[Q_1(x) - Q_2(x)]\Big\} \times \Big\{\frac{2Q_1(x)}{l}[Q_1(x) - Q_2(x)] + 2Q_3(x)\Big\} = 0 \quad . \quad (15)$$

When like powers of x are collected, this is a sixth-order equation in x, and we must now find the appropriate root of this equation.

An approximate value of the required root is found by considering the pull-out condition of two cylindrical-rotor machines.

Here $$x = \frac{X_{d2}V_{01}}{X_{d1} + X_{d2}}$$

Hence, starting with this as an approximation, we can find accurately the root of eqn. (15) which lies near this value. Having found x, we now find z from eqn. (12), and when z and x are known, y is easily found from

$$y^2 = z^2 - fx^2 - gx - h$$

Hence $$P' = y\frac{(V_{01} + \beta x)}{X_{d1}}$$

from eqn. (11).

The terminal voltage at pull-out is $V' = \sqrt{(x^2 + y^2)}$.

The pull-out angle δ_1' is given by $\tan \delta_1' = y/x$.

The pull-out angle δ_2' is found by dividing eqn. (8) by eqn. (9), and the current I' and power factor $\cos\phi'$ at pull-out may be found from the equations given in Reference 1.

[If, as in Fig. 3, the over-excited machine is machine 1, the approximate root is always less than the accurate root of eqn. (15). This removes any doubt as to which root of eqn. (15) is the appropriate one.]

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The Institution of Electrical Engineers
Paper No. 2443 U
Feb. 1958

TWO IMPROVED CHORDED WINDINGS FOR 3 : 1 POLE-CHANGING

By Prof. G. H. RAWCLIFFE, M.A., D.Sc., Member, and N. L. GARLICK, Associate Member.

(*The paper was first received* 17*th July, and in revised form* 10*th September*, 1957.)

SUMMARY

The paper describes two further and improved 3:1 pole-changing windings which both have only nine control leads, and in which a 60° spread has been used, instead of the 120° spread which was used in a machine previously described. A particular feature of these windings is that the coil pitch is critical, and can have only one value. Full-pitched coils cause very bad crawling effects.

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(1) INTRODUCTION

An earlier paper[2] described a new 3:1 pole-changing winding in which a 120° phase spread was used, principally in order to avoid crawling tendencies when connected for the higher speed, in which connection one-third of the whole winding was omitted. In the discussion before The Institution, it was asked whether the possibility of using a 60° phase spread, with correctly chosen chording, had been considered. The reply then given was that such a winding was already under construction; and that, if it proved satisfactory, it would form the subject of a short paper. The present paper describes the results which have been obtained,[1] showing that the 60° spread machine compares favourably with the previous one having a 120° spread. There are two distinct ways of making this final winding. One gives the best performance but is a little more difficult to wind: the other gives slightly less good performance but can be made by standard methods.

(2) THE EFFECT OF CHORDING

It is shown from Figs. 5 and 10 of Reference 2 that 11 control leads are necessary for a 120° spread winding using the pole-tripling principle, but that 9 control leads are sufficient for a 60° spread winding. The complexity of the control gear is, of course, also correspondingly reduced in the latter case. There is therefore a *prima facie* case for using a 60° spread, if possible. An earlier patent[3] actually proposed this arrangement, but stated that a single-layer full-pitch winding could be used. The authors have found by test, supported by theoretical analysis, than an induction motor with such a full-pitch 60° spread winding crawls badly; and they therefore decided first to consider and to test a full-pitch winding connected with 120° phase spread. This gave admirable performance, as recorded in Reference 2, and in the corresponding patent.[4]

Another identical stator was then wound with a winding just like the first, except that its coil pitch was 1–9 (8 slots) instead of 1–10 (9 slots). The winding was wound and connected for 60° spread as shown in Figs. 1 and 2, and it was tested as before, with the results given in Section 5. Overall, it can here be stated that the new machine gave a load performance slightly better than the former machine; and that it has two fewer control leads and rather less copper in its end windings, and is therefore to be preferred economically to the original machine.

Before the new machine was wound and tested a full theoretical

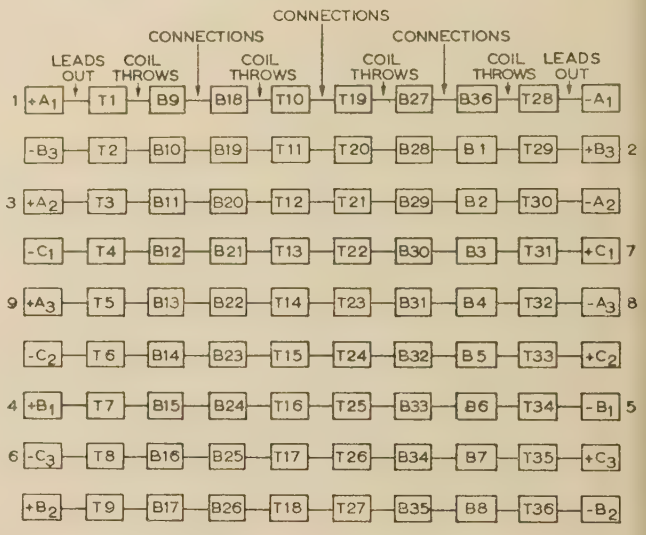

Fig. 1.—Winding diagram for 12 : 4 pole-changing motor.

36 slots.
36 coils 60° phase spread.
Eight-ninths of full pitch = slots 1–9, etc.
T = Top.
B = Bottom.

The slots are numbered consecutively.
Connect into nine sets of four coils, and then join to give nine leads out (marked 1–9).

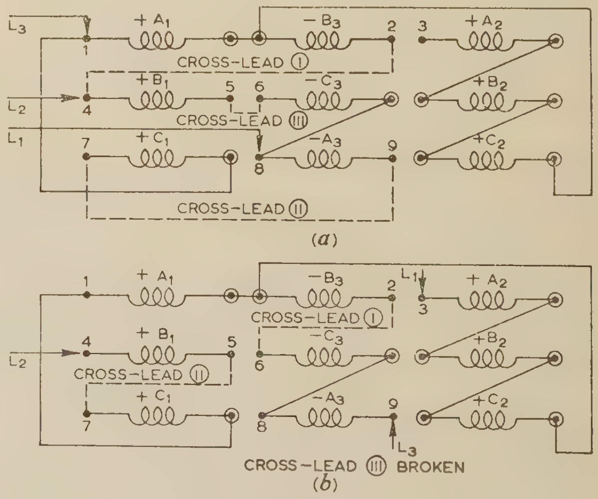

Fig. 2.—3:1 pole-changing winding (60° spread).

With connections modified to reduce the number of leads to nine.

---- Switch connections.
—— Fixed connections.

In the prototype machine 18 leads are brought to the terminals.
Nine terminals marked ⊙ can be made into fixed connections.
Nine terminals marked • must be brought out to leads (see Fig. 1).
A six-gang double-throw switch is required to start and change speed. (3 gang for cross-leads. 3 gang for main supply.)

(*a*) Connections for high-speed running.
(*b*) Connections for low-speed running.

Written contributions on papers published without being read at meetings are invited for consideration with a view to publication.

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analysis was made, with the results which are given briefly in the following Sections.

(2.1) Winding Factors for 12 Poles, for 120° Spread—Full Pitch; and 60° Spread—Chorded to Eight-Ninths Full Pitch

The winding factor for the earlier machine,[2] for 12 poles, can readily be seen to be $\sqrt{3}/2$. For the new machine, the coil pitch of 8 slots is equivalent on a 12-pole basis to 60° of short-chording, and the winding factor is again $\sqrt{3}/2$. The 12-pole magnetic loading is thus unaltered, although the end connections are a little shorter, and the heating is correspondingly less. It therefore became possible to concentrate attention on the 4-pole performance where difficulties were most likely to occur.

(2.2) Winding Factors for 4 Poles, for 80° Spread—Full Pitch; and 40° Spread—Chorded to Eight-Ninths Full Pitch

The fundamental m.m.f. due to two-thirds of a 120° spread full-pitch winding has been previously shown in Fig. 9 of Reference 2 to be given by

$$\frac{36\sqrt{2}}{\pi^2}\cos^2\frac{\pi}{6}\sin\frac{\pi}{9}\cos\frac{\pi}{9}\times I_aN \text{ ampere-turns per pole}$$

where N is the number of conductors per pole per phase actually in circuit (two-thirds of the total number), and I_a is the r.m.s. phase current.

The m.m.f. of a 60° spread winding, short-chorded by one slot in nine, when only 40° spread is used, is shown in Section 2.3 to be equivalent to that of a full-pitch winding, 60° spread, unevenly distributed over three slots in the ratio $\frac{1}{4}:\frac{1}{2}:\frac{1}{4}$. Thus the fundamental m.m.f. is given, as shown in Fig. 11 of Reference 5, by

$$\frac{36\sqrt{2}}{\pi^2}\cos^2\frac{\pi}{6}\sin\frac{\pi}{9}\cos\frac{\pi}{18}\times I_aN \text{ ampere-turns per pole}$$

It thus follows that the fundamental 4-pole m.m.f. of the new winding, compared with the original winding, is increased in the ratio

$$\cos\frac{\pi}{18}\Big/\cos\frac{\pi}{9}=\frac{0\cdot985}{0\cdot940}=1\cdot045$$

i.e. the conductors become slightly more effective.

In contrast to the 12-pole connection, a slight change of magnetic loading thus occurs when changing the type of winding, but it is still a very small one. It can therefore be concluded that the overall effect on the fundamental flux at both speeds, when changing from 120° spread—full pitch to 60° spread—chorded to eight-ninths, will be a very slight reduction in flux density at the higher speed for the same voltage. The harmonic fluxes are, however, greatly affected, as will be shown in Sections 2.3 and 2.4.

(2.3) Equivalence of the New Winding to a Non-Uniform Standard-Type Winding

In Fig. 3 are shown the remaining portions of a normal 60° spread winding, chorded to eight-ninths of full pitch, when the end coil of each three is omitted. An inspection of this diagram will immediately reveal that the resultant distribution of the conductors in any phase band covers the full 60°, even though the spread per coil group is only 40°; but that the relative conductor distributions over a phase band are $\frac{1}{4}:\frac{1}{2}:\frac{1}{4}$. Further, the distance between the centre of one phase band and the centre of the next is one pole pitch. The winding is therefore equivalent to a full-pitch 60° spread winding, with a non-uniform distribution of the conductors. Such a winding has already been designed

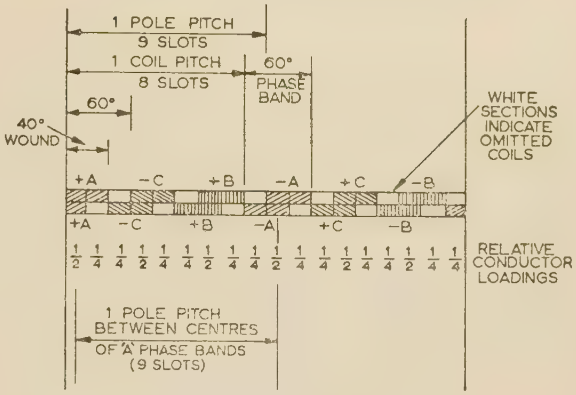

Fig. 3.—Equivalence of eight-ninths chorded winding two-thirds wound and full-pitch winding unevenly distributed.

for other purposes and was described in a previous paper.[5] Its harmonic content was there examined, the fundamental component being as stated above.

(2.4) Chording and Harmonics

The effect of slight chording is, however, very different where harmonics are concerned. The chording factor for the mth harmonic, when a winding is short-chorded by one slot in nine, is $\cos m\pi/18$; and for $m = 1, 5, 7, 11, 13, 17$, etc., $\cos m\pi/18$ has the respective values $0\cdot985$, $0\cdot643$, $0\cdot342$, $-0\cdot342$, $-0\cdot643$, $-0\cdot985$, etc. It will therefore be seen that the only harmonics (notably the seventh) which are ever of such a magnitude as to cause any trouble are much reduced in relative magnitude by this degree of chording.

The harmonic series for the original unchorded winding was shown in Fig. 8 of Reference 2 to be given by

$$a_m=\frac{36h_1}{\pi^2m^2}\cos^2\frac{m\pi}{6}\sin\frac{m\pi}{9}$$

where h_1 is the amplitude of the wave; whereas that for a winding equivalent to the chorded winding was shown in Fig. 11 of Reference 5, by direct analysis, to be given by

$$a_m=\frac{36h_1}{\pi^2m^2}\cos^2\frac{m\pi}{6}\sin\frac{m\pi}{9}\cos\frac{m\pi}{18}$$

It will be observed that the second series could have been derived directly from the first by applying the general chording factor, $\cos m\pi/18$.

The amount of chording proposed is the only possibility if there are only three slots per pole at the lower speed. Short-chording by two slots would be equivalent to a winding of only one-third full pitch at the higher pole-number, and would make the winding grossly over-chorded; and short-chording by three slots would give a winding of zero effect. A full-pitch winding gives a serious seventh-harmonic torque, as discussed in the earlier paper, and hence it is essential to chord this winding by exactly one slot, if 60° spread is to be used. If there were more slots per pole other possibilities would arise, but any further modification could readily be dealt with on similar lines.

It is, however, a matter of considerable interest that the seventh-harmonic content of the m.m.f. of this new winding is considerably smaller than in a standard industrial full-pitch winding; and it is thus not surprising that the practical improvement produced by short-chording of only one slot was enormous. There was, in fact, no suggestion of crawling, even when starting against a heavy torque.

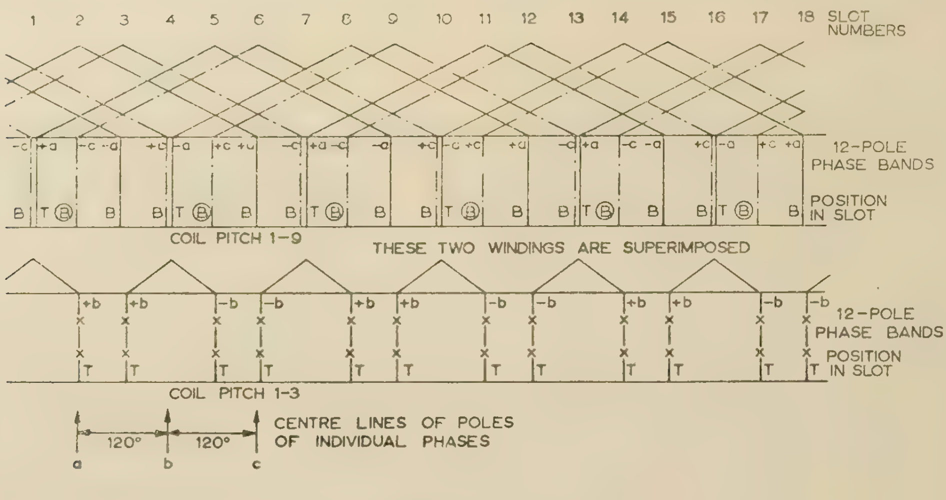

Fig. 4.—Final winding diagram.
One phase with 12-pole coil pitch.
(B) = Coil sides pushed down in slots.
T = Top of slot.
B = Bottom of slot.

(3) A FURTHER SIMPLIFICATION OF THE WINDING

A further simplification of this winding is, however, possible. An inspection of Fig. 3, which illustrates the basic 4-pole winding, will show that it is possible, in every third slot, to push to the bottom of the slot a coil side, which, in the normal sequence, would be at the top of the slot. If this is done, the upper halves of two slots out of three are left empty, and it becomes possible to wind the third phase of the 12-pole winding with a coil pitch of 1–3, or 2 slots, as shown in Fig. 4. This has the advantage of considerably reducing the weight of copper used in the end windings of the third 12-pole phase, and also the resultant copper losses. At the same time, it makes the pitch of the conductors for this third phase equal to two-thirds of full pitch, i.e. $2\pi/3$, in relation to a 12-pole field; the number of conductors per coil side in this phase must therefore be the same as the conductors per coil side in the rest of the winding, which has a pitch of

$$\frac{8\pi}{3} = 2\pi + \frac{2\pi}{3}$$

both pitches thus being electrically identical.

It is therefore believed that technically the best possible form of 3 : 1 pole-changing winding is as shown in Fig. 4, in which two-thirds of the whole winding—used both in 4-pole and 12-pole operation—has a coil pitch of 8 slots, and one-third of the winding—used only for 12-pole operation—has a coil pitch of 2 slots. Such a machine was wound and tested, in addition to a normal machine with 36 identical coils chorded to eight-ninths full-pitch, and the results are given together in Section 5.

Even though the performance of this final form of the machine is better than that of the semi-final form, in which all the coils are identical, it might nevertheless happen that the latter was more acceptable for small mass-produced machines; as it involves no special skill in winding, and is exactly comparable to many windings now made in mass-production shops. In small machines, wound with mush windings, it is most unlikely that there would be any difficulty in shaping the coils to construct the latest modification of the winding, though there might be in larger machines, with formed coils. Points of this kind can, however, only be settled with reference to the actual constructional details of the type of machine involved; and they are, in any event, irrelevant to the principles involved. Whichever method of construction is used, the connections and operation are the same, though the performance and rating are slightly better with the final modified construction.

(4) M.M.F. WAVEFORMS FOR 4 POLES

A 4-pole winding with this special distribution will necessarily give a waveform different from that for a uniformly distributed winding. In a previous paper,[5] the comparative analyses for both windings were carried out, the phase bands being considered as uniform current-sheets. It was there found, on this basis, that the new winding had somewhat larger 5th and 13th har-

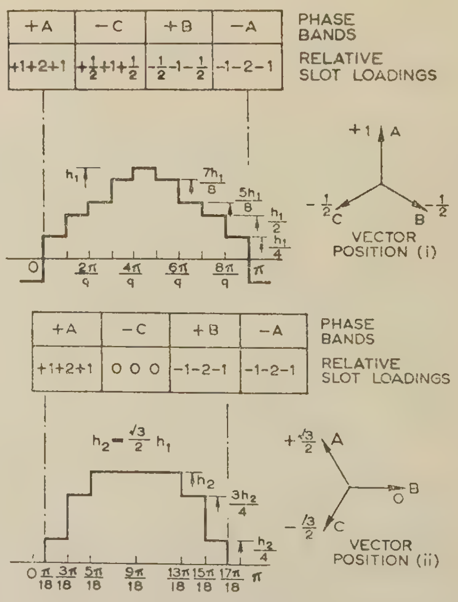

Fig. 5.—Stepped waveforms of new windings for four-pole connection.

The Fourier analysis of both these waves is $y = \frac{3h_1}{\pi m}\cos^2\frac{m\pi}{18} = \frac{2\sqrt{3}h_2}{\pi m}\cos^2\frac{m\pi}{18}$ with all signs positive in position (i) and sign sequence $+ - - +$ in position (ii)

$$y = h_1(0\cdot926 \sin\theta \pm 0\cdot079 \sin 5\theta \pm 0\cdot016 \sin 7\theta + 0\cdot010 \sin 11\theta + 0\cdot030 \sin 13\theta \pm 0\cdot054 \sin 17\theta \pm 0\cdot049 \sin 19\theta + \ldots$$

monics, but smaller 7th and 11th harmonics, compared with a standard winding. All other harmonics for both windings were negligible.

Further comparative analyses have also been carried out for both new and standard windings with 3 slots per pole per phase, taking waveforms stepped at each slot. The results for the new winding are shown in Fig. 5, whereas the corresponding results for a standard winding with this slotting are

$$y = h_1(0{\cdot}917 \sin\theta + 0{\cdot}042 \sin 5\theta - 0{\cdot}024 \sin 7\theta - 0{\cdot}016 \sin 11\theta + 0{\cdot}016 \sin 13\theta + 0{\cdot}054 \sin 17\theta + 0{\cdot}048 \sin 19\theta \ldots)$$

It is clear that this method of analysis shows similar results, the 7th and 11th harmonics being smaller, and the 5th and 13th larger, in the new winding as compared with a standard winding. The chief difference which appears in both the step-by-step analyses is that the slot harmonics, of orders $(2S \pm 1)$, are made apparent, where S is the number of slots per pole, i.e. 9 in this machine. It may therefore be said that, overall, the conclusions from a theoretical analysis of this winding are just as favourable as its operation was found to be in practice.

(5) TEST RESULTS ON THE TWO NEW WINDINGS

(5.1) No-Load Tests

The usual open- and short-circuit tests were performed for the original full-pitch winding and for the two new chorded windings. (The winding in which all the coils are the same will be called the 'first chorded winding', and the winding which has one 12-pole phase composed of smaller coils will be called the 'second chorded winding'). The results were generally in accordance with the theory given above, and may be summarized as follows.

(5.1.1) Tests for 12 Poles.

The three magnetizing curves, for the original machine and for the two machines with one or other of the two chorded windings, are a little different from first-order theory, and are shown in Fig. 6.

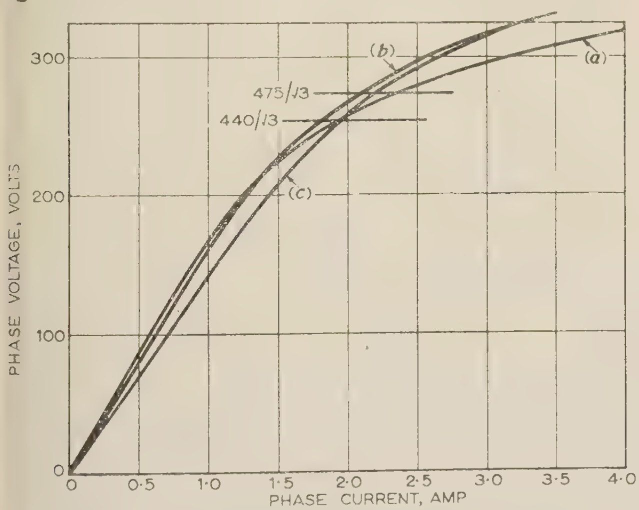

Fig. 6.—Magnetization curves; 12-pole star connection.
(a) Original machine: 120° spread full-pitch winding.
New machine { (b) First chorded winding: 60° spread. (c) Second chorded winding: 60° spread.

As predicted in Section 2.1, since the corresponding winding factors were the same, the initial slopes of the magnetizing curves for the original winding and the first chorded winding are almost identical. That for the original winding is very slightly steeper, probably owing to the second-order effect of its larger leakage reactance.

Towards saturation, the magnetizing current of both the chorded windings becomes substantially smaller than that of the original winding. This result, of course, is of considerable practical significance, and is very favourable to the new windings. It is always difficult to give conclusive explanations of phenomena in the saturation range, but a probable reason for this difference is that the distribution of conductors in the original winding was less favourable in relation to harmonic saturation than it was in the new chorded windings. Another possible reason is the small but sensible difference in leakage reactance. The numbers of conductors and the fundamental components of their distributions were identical in the three cases, and hence the near identity of the lower parts of the magnetizing curves.

On short-circuit, the second chorded winding showed the expected lower (average) leakage reactance, and consequentially this winding took sensibly the highest initial magnetizing current. Towards saturation, the magnetizing curves of the two chorded windings coalesced, since the magnetizing impedance progressively determines the performance as the voltage rises.

These three curves therefore display a small though definite advantage in the chorded windings, as they make it clear that either of them can be worked at a rather higher voltage than the first winding. As was shown theoretically in the original paper,[2] the limit of voltage arises in the 12-pole connection, the machine being a little under-fluxed in the 4-pole connection. Any modification which permits the voltage to be raised for 12 poles will also be acceptable for 4 poles, and will improve the performance at both speeds.

(5.1.2) Tests for 4 Poles.

The first and second chorded windings gave absolutely indistinguishable no-load results, and both of them permitted the use of a slightly higher voltage than the original winding, without causing excessive magnetizing currents. This corresponds with the 4·5% improvement predicted in Section 2.2, the improvement in overall performance being roughly proportional to the square of the increase of voltage. On the other hand, both chorded windings have a slightly higher leakage reactance than the original winding, which tended to offset the improvement in performance which arose from the increased voltage. Altogether, the change in performance for 4 poles was extremely small.

There was, however, a special reason for obtaining the 4-pole magnetizing curves of the two chorded machines. Had there been accidental differences, especially in air-gap, between the two machine frames which were nominally identical, this might well have explained the small observed difference between the 12-pole magnetizing characteristics. Since the 4-pole magnetizing characteristics were indistinguishable, however, the difference for 12 poles cannot be due to manufacturing tolerances.

(5.2) Load Tests

Full-load tests were performed on three machines with identical frames and identical numbers of conductors per slot, but wound and connected in three different ways:

(a) Original winding, full-pitch, 120° spread.
(b) First chorded winding, eight-ninths full-pitch, 60° spread.
(c) Second chorded winding, eight-ninths full-pitch, 60° spread, one 12-pole phase wound with small coils only.

The first machine was tested at a slightly lower voltage, for the reasons explained in Section 5.1.1. The results obtained are shown in Table 1.

It can be seen that machine (c) gave, as would be expected, the best performance; and that machines (a) and (b) give very nearly the same performance. Machine (b) would always be

Table 1

LOAD TESTS ON THREE MACHINES

	Machine (*a*)	Machine (*b*)	Machine (*c*)
Line voltage, volts ..	440	475	475
Output on 4 poles, h.p.	4·0	4·1	4·2
Full-load slip, % ..	6·7	6·7	7·0
Full-load efficiency, %	80	80·5	81·5
Power factor	0·88	0·88	0·88
Output on 12 poles, h.p.	0·81	0·82	0·90
Full-load slip, % ..	10·0	8·5	9·0
Full-load efficiency, %	57	57·5	58·5
Power factor	0·58	0·54	0·56

preferred to machine (*a*); and machine (*c*) would be still further preferred if the small extra manufacturing difficulties were considered negligible.

(5.3) Rotor with New Slotting

When the original paper was read,[2] several speakers suggested that 44 rotor slots would be preferred to 48, in combination with 36 stator slots. (The number 48 had been accepted in an existing frame.) A further rotor with 44 slots, but otherwise identical, was manufactured and tested in the three machines mentioned above, but there was no discernible difference in performance or noise level at either speed.

(6) CONCLUSION

Whilst the 120° spread winding described earlier was entirely satisfactory in operation, these new chorded 60° spread windings are economically a distinct improvement. At the same time, the technical performance in most respects is slightly better; and the new winding, in one or other of its two forms, is therefore more suitable than the original 120° spread winding for industrial application. Even though the improvement in performance of the first chorded machine is only marginal, it is obtained without any opposing disadvantages; and the reduction, from 11 to 9, in the number of control leads for both machines is a very solid practical advantage, as it reduces the cost of the necessary control gear. The 3 : 1 pole-changing motor can now be regarded as a satisfactory industrial machine, which may be more suited to some duties than the 2 : 1 machine now commonly used.

(7) ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance they have received from Newman Industries, Ltd., Yate, Bristol, especially in relation to the supply of special components and materials at intervals throughout the investigation.

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(3) MAYER, V.: 'Improvements in or Relating to the Windings of Dynamo-Electric Machines', British Patent No. 579400.
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Reference 2 contains a number of references to earlier related work and may be consulted if desired.

21.315.221

The Institution of Electrical Engineers
Paper No. 2484 U
Feb. 1958

THE CASE FOR OPEN INSTALLATION FOR METAL-SHEATHED CABLES, WITH SOME NOTES ON CONSTRUCTION

By W. HOLTTUM, M.Eng., Member.

(*The paper was first received* 24*th May, and in revised form* 19*th October*, 1957.)

SUMMARY

The paper is an extension of the author's earlier paper which gave details of the incidence, together with an explanation, of the large amount of sheath fracture experienced with lead and lead-alloy sheathed cables run on hooks. The conclusion was reached that, with correct design, satisfactory life can be obtained for cables so installed.

As a result of that work the author has been led to the further conclusion, briefly recorded in the discussion on the earlier paper, that, contrary to the common view, installation on spaced supports is preferable to any other method where this alternative is available.

The reasons for this conclusion are discussed, and the consideration of construction on spaced supports is extended both as to method and analysis of behaviour. A new method, employing pairs of supports instead of single ones, is described.

The principles and conclusions are applicable to lead- or aluminium-sheathed cables of solid, oil-filled, or gas-pressure type, and to communication cables.

(1) INTRODUCTION

The belief is commonly held that burying in the ground is the method of installation giving the most generally satisfactory conditions for cable operation. This is recorded in an earlier paper,* but, as a result of that work, the author reached the conclusion that this view is much too superficial. A strong case can be made out for the installation of metal-sheathed cables on spaced supports in preference to burying in the ground or any other method of continuous support in those cases where site conditions permit, and, if in the open, at least up to the temperatures experienced in this country.

The reason for the general preference for burying cables, irrespective of necessity, is far from clear, but it is probably supported by an involuntary feeling of 'out of sight, out of mind', as well as a prejudice in favour of common practice. It is probably not contributed to by the trouble with open installation, since it has not been generally known, but sheath fracture due to too short spacing of supports has caused the latter construction to be viewed in some quarters with quite unwarranted disfavour. It is clearly very desirable that a correct assessment of possible alternatives should be established.

Laying in the ground involves a number of hazards. Open installation virtually eliminates them at the expense of others much less serious, and greatly reduces the cost of maintenance.

With duct installation, little used for power cables in this country unless unavoidable, expansion must cause irregular snaking, more concentrated than when laid on a flat surface; and while flexing directly leading to sheath fracture at joints may be prevented by avoiding manholes with bends and keeping the joints in line with the cable, the construction is, in the author's view, undesirable. This objection does not, of course, apply to telecommunication cables.

* HOLTTUM, W.: 'The Installation of Metal-Sheathed Cables on Spaced Supports', *Proceedings I.E.E.*, Paper No. 1814 U, April, 1955 (102 A, p. 729).

Written contributions on papers published without being read at meetings are invited for consideration with a view to publication.
Mr. Holttum is retired from British Insulated Callender's Cables Ltd.

Since burying of cables must doubtless remain the standard method of installation in public roads and footways, it should be made clear that the aim of the paper is not to detract from this method, which would indeed be futile in view of experience and necessity. The aim is to show that installation on spaced supports is not to be regarded as something to be avoided whenever possible, but, on the contrary, as being preferable where site conditions permit its adoption.

While, in the majority of cases, alternative methods or routes to provide them are not available, cabling along railways is a notable exception. Considerable amounts of cable have been installed in concrete troughing and in asbestos-cement ducts, and recognition that installation in hooks on posts or walls is technically at least as good would enable an important saving to be made in the cost of railway electrification so far as cabling is employed. Thorough examination of the matter is called for, since experimental determination is impracticable. Any kind of accelerated test could not be relied on, so that, among other difficulties, a prohibitive time would be required.

The arguments in the paper are applicable to gas-pressure and oil-filled cables as well as to the solid type, and also to aluminium-sheathed cables unless the context indicates otherwise.

The opportunity is taken to extend the application of engineering principles to construction on spaced supports.

(2) THE RELATIVE ADVANTAGES OF BURYING AND OPEN INSTALLATION

The following disadvantages of burying over open installation cannot be disputed:

(*a*) Greater installation cost.
(*b*) Risk of sheath corrosion, either chemical or electrolytic.
(*c*) Accelerated deterioration of protective coverings.
(*d*) Possibility of damage by excavation by other authorities.
(*e*) Possibility of damage by subsidence.
(*f*) Much increased probability of penetration of moisture through any defect in the sheath or sealing of the joint.
(*g*) Delay in carrying out repairs through the time taken in fault location and excavating.
(*h*) High cost of repairs due to excavation and reinstatement.

While the probability of incidence of some of these hazards is low, together they are a heavy potential liability. All except (*e*) are disposed of by open installation, but (*d*) is replaced by the possibility of accidental or wanton damage, unlikely on sites considered suitable. Rectification of subsidence can usually be made before damage occurs.

Positive advantages of open installation are that provision can be made for cables to be added later with a minimum of installation cost, and any joints which may come under suspicion are easily checked.

With cables along railways the risk of fire has not been found prohibitive in the past, and electrification will reduce it.

Damage by derailments can be kept to a minimum by running the post line as far as possible from the track, and may be less than with surface concrete troughing, which is usually placed near the track.

There are two other points dealt with in detail later.

Installation in air generally gives higher current rating, but not when exposed to sun.

Buried cables experience severe longitudinal stresses owing to expansion and contraction with changes of temperature. On spaced supports these are relieved, but, for lead-sheathed cable, strain of the sheath beyond its elastic limit caused by cyclic bending takes its place. It is shown that this can be made no more severe than the stress when buried.

(3) ECONOMIC ASPECT WITH REGARD TO CURRENT RATING

While open installation gives, for the larger conductor sizes, higher current-carrying capacity with the standard ambient temperature of 25° C, and in some cases will allow a reduction in conductor size, this is not so for cables exposed to sun. For these no standard current ratings exist, the point being dealt with in E.R.A. Report Ref. FT/183 by the recommendation that cables should be shielded from direct rays of the sun without restriction of ventilation. Increase of conductor size will generally be a more economical way of maintaining current-carrying capacity than sun shielding.

Table 1 shows, for a representative selection of solid-type cables, the standard ratings buried for a ground thermal resistivity of 120 (deg C/cm)/(watt/cm^2) and in air from E.R.A. Report Ref. FT/183, ratings for exposure to sun, and the increased conductor sizes required for cables exposed to sun to cover the ratings buried, these last two being calculated.

Table 1

CURRENT-CARRYING CAPACITIES, BURIED AND EXPOSED, OF 3-CORE ARMOURED CABLES TO B.S. 480

	1·1 kV belted		11 kV screened		33 kV screened	
Size, in^2	0·1	0·75	0·1	0·3	0·1	0·4
Rating buried, amp	240	680	215	395	205	420
Rating in air, sheltered, amp	225	750	220	435	215	485
Rating exposed to sun, amp	173	582	171	338	168	379
Larger cable for exposure to sun: Size in^2	0·2	1·0	0·15	0·4	0·15	0·5
Larger cable for exposure to sun: Rating, amp	266	685	215	396	208	425
Rating buried, amp	345	760	265	460	250	460

(4) STRESSES DUE TO EXPANSION IN BURIED CABLE

A buried cable, being a static object with no applied longitudinal load, gives a misleading impression of being unstressed, and it is important to consider the quite-serious stresses caused by thermal expansion and contraction.

A cable buried in the ground on a fairly straight run is unable to move in any direction. Thermal changes therefore cause stresses to build up, which, in the case of lead sheath, far exceed the elastic limit of the material, and for the other metal components may theoretically approach or even exceed it. Table 2 shows the position, assuming the same temperature for aluminium as for copper and lead for the same purpose.

The strain beyond the elastic limit will be the attempted expansion or repressed strain minus twice the elastic strain, since the latter will operate in both directions.

An example is given in Section 11.1.

It will be seen from Section 9 that the value of 5 for the yield stress of lead is probably high, if indeed any actual value exists. Any elastic strain is therefore a negligible part of the repressed strain.

For aluminium the elastic limit may be exceeded, but after initial straining it will settle down to an intermediate length, so that later cycles cause stress within the elastic limit. However, the load on joint assemblies can be severe. A sheath of 2 in outer diameter and 0·1 in thick, when strained 0·001 26/2 = 0·000 66 will exert a thrust or pull of nearly 4 000 lb.

The expansion of 3-core cable conductors cannot be accommodated in the spiral of the cores, as the lay is too long and the sheath clearance too small, while, in belted cables, radial movement is virtually prevented.

If the length of lay is n times the core pitch-circle diameter, d, and the fractional expansion is e, then, if a cable is unable to lengthen, conductor expansion will cause d to try to increase by the approximate factor $\sqrt{(2en/\pi^2 + 1)}$. n may range from about 40 to 100, giving this factor a range for 65° C rise of 1·17–1·83, or for 50° C, 1·13–1·67. Clearly, the pitch-circle diameter of the cores could, in no case, increase even by the amount required for the lowest value of n.

The cables with the highest temperature rise, i.e. up to 6·6 kV, are those in which the theoretical stress will be most nearly approached, since they are usually of belted construction.

Deformation due to mechanical stress has been found in conductor joints after heat-cycle testing of unburied cable, and service failures have been known involving pulled-out conductor joints and sheath fractures near plumbed wipes which could not be accounted for by subsidence.

It is clear, therefore, that the reduction of conductor stress is a highly desirable aim. Stress in wire armour is innocuous, and will fall further short of its theoretical value, which is lower than that for conductors.

(5) BEHAVIOUR OF CABLE ON SPACED SUPPORTS AND A NEW CONSTRUCTION

There is an instinctive feeling that continuous support is the correct engineering construction, and that a cable hung on spaced

Table 2

EFFECTIVE STRAIN DUE TO TEMPERATURE CYCLES IN BURIED CABLE COMPONENTS

	Coefficient of expansion per deg C	Yield stress	Modulus of elasticity	Range of working temperature rise	Repressed strain for range of temperature rise	Strain at yield stress
		lb/in^2	lb/in^2	deg C	in	in
Sheath: Lead	0·000 029 3	5(?)	$2·6 \times 10^6$	20–55	0·000 586–0·001 61	0·000 002
Sheath: Aluminium	0·000 023 0	10 000	10×10^6	20–55	0·000 460–0·001 26	0·001
Conductor: Copper	0·000 017 7	17 000	18×10^6	50–65	0·000 885–0·001 15	0·001
Conductor: Aluminium	0·000 023 0	10 000	10×10^6	50–65	0·001 15–0·001 49	0·001
G.I. armour wire	0·000 011 7	22 000	22×10^6	18–48	0·000 211–0·000 562	0·001

supports is somehow being ill-treated. If there were no expansion and contraction this view would be sound, but stresses due to thermal changes make the continuously-supported cable the one which is being ill-treated, while the festooned one works under comfortable conditions.

The ideal way of accommodating expansion would be by uniform curvature of large radius. For straight runs this would take the form of circular arcs between points of inflection, but a cable will not naturally fall into circular arcs, and the efficiency of any particular form is indicated by the ratio of maximum to mean curvature, or 'curvature ratio', which should be as low as possible.

A continuously supported but unrestrained cable will develop irregular bending with local concentrations. Installation on shelves in station work and in wood troughing on posts has, so far as the author is aware, given generally satisfactory service, but continuous support is to be regarded as inferior to constructions giving regular formation, as by gravity sagging in equal spans, each taking up its own expansion. Attempts have been made to arrange horizontal deflection, the cable being supported at each mid-span and given an initial displacement in opposite directions in alternate spans, so that expansion is taken up by lateral sliding on the intermediate supports. The arrangement has a theoretical merit which has probably escaped notice. Since each span behaves as a collapsing strut, the curvature ratio is $\pi/2 = 1\cdot57$. The method is, however, expensive, and requires gripping cleats and the intermediate supports; it is laborious to install, liable to irregular operation, and has no practical advantage to commend it.

For gravity sagging the curvature ratio is $2\cdot60$. While there is no reason to consider this rather high value detrimental, there is a method* by which it can be substantially reduced. If each support is replaced by two a short distance apart mounted so that they are free to tilt with the cable, the bending at the supports will nearly all be distributed over the lengths spanning each pair. The optimum spacing between the members of a pair may be shown to be $0\cdot284$ times the pitch of the arrangement, and the curvature ratio is then $1\cdot54$, i.e. slightly better than for a strut. Any ratio of pair spacing to pitch from $0\cdot2$ to the optimum will give nearly the full benefit obtainable from this construction. A ratio of $0\cdot1$ will give material benefit, and may be convenient to enable each pair to be mounted on the same structure. The method is gone into more fully in Section 11.2.

It was shown in the earlier paper that the minimum support spacing for satisfactory operation with gravity sagging is that for which the weight of the cable is just able to cause sufficient sag to take up the expansion. Increase of spacing beyond this value at first reduces both the curvature and the change of curvature with expansion, and is therefore beneficial. With increase beyond some value, however, a stage will be reached at which the cable tends to take the form of a catenary instead of a beam, and different conditions are then introduced. Diminishing curvature and change of curvature (both unimportant in amount) continue in the catenary loop, but as the span, and therefore the tension for a given ratio of sag to span, is increased, flexing tends to concentrate near the supports, and this calls for consideration.

Therefore, while increase of span is beneficial if a cable is behaving as a beam, it becomes undesirable when it starts to behave as a catenary. It follows that there is an optimum spacing, this being the maximum at which beam formation persists. No method of determining this value can be suggested, but it would appear reasonable to take it as between $1\frac{1}{2}$ and $2\frac{1}{2}$ times the minimum calculated span.

It is, however, important, in the interests of economy, to consider whether this more concentrated flexing near supports can be sufficient to be detrimental or can be minimized.

* British Patent Application No. 24363. 1955.

Fig. 1 shows, for a catenary, the slope at the ends, the change of slope for $0\cdot05\%$ expansion, the tension, and the fractional

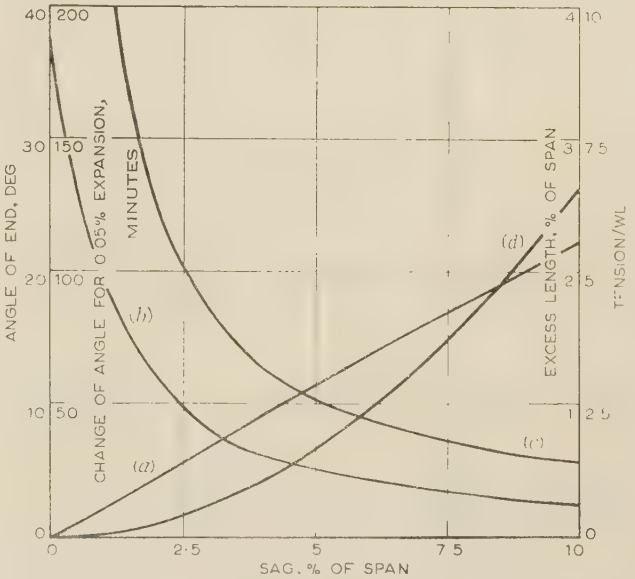


Fig. 1.—Characteristics of catenary.

(*a*) Angle of end.
(*b*) Change of angle for $0\cdot05\%$ expansion.
(*c*) Tension/WL. W = Weight per unit length. L = Span.
(*d*) Excess length as a percentage of span.

difference between length and span, for sags of up to 10% of the span. It will be seen that the change of slope varies from over 3° for zero sag to under $0\cdot5^\circ$ for 5% and under $0\cdot2^\circ$ for 10%.

Five per cent may be regarded as a reasonable sag, and, while the change of slope of 0° 26′ is very small, the strain depends upon the length over which it occurs. The stiffness of the cable must cause the flexing to be distributed over some length. The matter is examined in Section 11.1, and the important conclusion is reached that the strain can be made no more than the repressed expansion in the sheath of a buried cable. Moreover, only a small portion of the sheath is subjected to these strains, whereas the whole of the sheath of a buried cable is affected.

If the span is further increased so that the weight is too great to be taken by short straight supports, it becomes necessary to provide longitudinally curved supports to fit the cable and the span formation, and distributed flexing over the support length is no longer possible.

There are thus four distinct principles on which spaced supports may be arranged, as shown in Fig. 2:

(*a*) Beam construction, up to spans not greatly exceeding the minimum permissible.
(*b*) Partial catenary construction with single supports, for spans up to some greater maximum.
(*c*) Double supports, for distributed flexing.
(*d*) Long span construction, with curved supports.

Judgment must be exercised in determining the span limits for each, though discrimination between (*a*) and (*b*) is not important as the construction is the same. It would appear reasonable to regard (*a*) as applicable up to $1\cdot5$ times the minimum span, (*b*) from $1\cdot5$ to $2\cdot5$, (*c*) up to 3 times, and (*d*) for longer spans up to the permissible tension in the cable. The last case is further considered in the next Section.

Method (*c*) has been investigated by erecting two spans of $\frac{1}{4}$ in outer-diameter pipe with supports pitched at 50 in, both

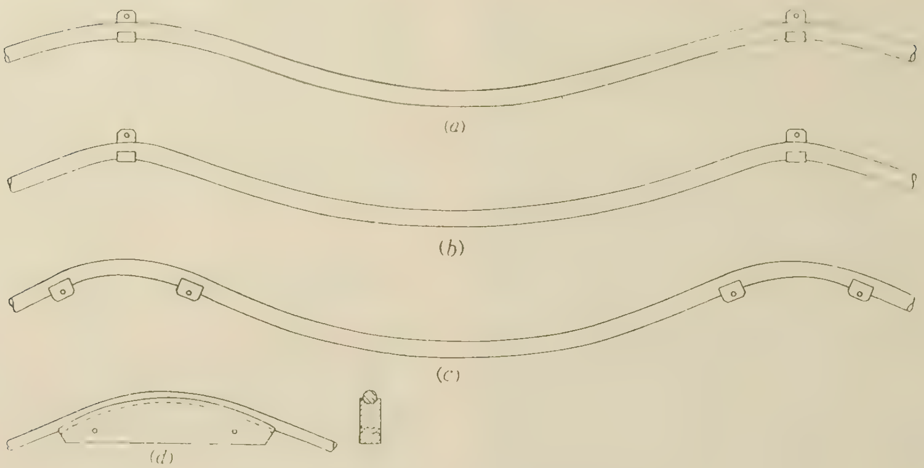


Fig. 2.—Forms of cable spans and supports.

(*a*) Beam.
(*b*) Partial catenary.
(*c*) Double support arrangement.
(*d*) Support for long span (catenary formation).

with double supports with optimum spacing and with single supports, and moving the supports to give the equivalent of 20 times the normal expansion to give an observable effect. Fig. 3 shows the forms taken at the centre support, and the much more distributed bending with double supports is apparent. The experiment is described in more detail in Section 11.3.

In the author's opinion, the double-support construction is the nearest practicable approach to the ideal, though it is not claimed that the extra cost over single supports is justified.

Double supports, if pivoted beneath the cable, should be of axial length not less than the cable diameter to discourage upsetting during erection or in the early stages of operation. Convenient constructions are in cast block or bent strip, or, if on brackets, cast saddles with trunnions level with the cable centre-line.

(6) LONG-SPAN CONSTRUCTION

Long spans with supports as shown in Fig. 2(*d*) could be used in many cases to avoid the need for cable bridges or catenary support, and the length of span need only be limited by the permissible tension in the cable.

The supports, which can conveniently be of cast aluminium, should be designed for bearing pressure and bending radius, and the tension taken by a mining-type cleat.

If tension is liable to be transmitted to a joint, wire armoured cable should be used and the armour tensioned across the joint.

(7) CONSTRUCTION ON BRIDGES

There is no criterion for the degree of vibration which can be harmful. On masonry bridges any special provision is uncalled for, wall-mounted hooks being used, or, if along the top of the wall, wood blocks to provide for the normal span and sag.

The first method to counter vibration on steelwork bridges is to increase the sag, as a span with substantial sag will vibrate less freely than one which is fairly tight. A sag of 10% is suggested, which requires about $2\frac{1}{2}$% extra length. A gripping cleat is required where a change of span or sag causes change of tension.

Where vibration is considered to be severe, raw-hide hangers may be used with normal span and extra sag.

Expansion movement at the ends should be dealt with by a

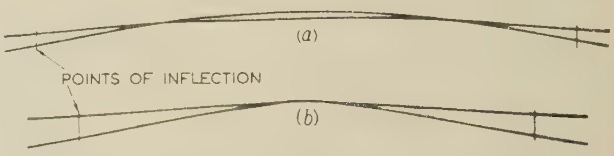


Fig. 3.—Movement owing to expansion of 1%.

(*a*) Double supports.
(*b*) Single supports.

long span with large sag from the last support on the bridge to the first beyond it.

(8) DESIGN AND ARRANGEMENT OF SUPPORTS

While the paper deals primarily with horizontal and fairly straight runs, every open cable run should be the subject of rational design, and it has been shown that economical construction and sound design go hand in hand.

An instructive example is the case of a change of level in a horizontal run by a short vertical one. Fig. 4 shows (*a*) conventional and (*b*) rational ways of arranging this. The latter contains only half as many supports, and lateral accommodation for expansion is available throughout. Supports B, C, and D should be pivoted and grip the cable, and A and E can be fixed and open.

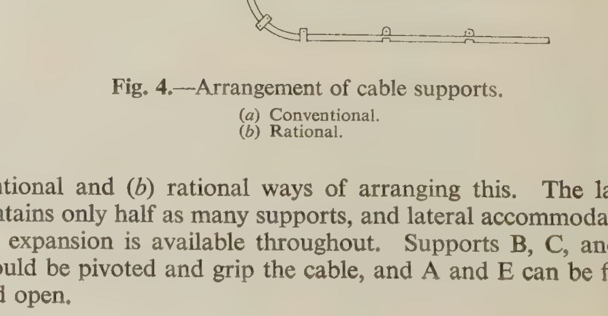


Fig. 4.—Arrangement of cable supports.

(*a*) Conventional.
(*b*) Rational.

Supports should always be at the natural angle of the cable so as to give even pressure. The simplest form of tiltable support is a hook of bent strip with single bolt fixing, but this is not self-adjusting, and cable movement during the settling-down period may cause tilting so that the cable rests on an edge. Such hooks should be kept under observation until stability is reached.

A complete range of supports should comprise the following types, for single cables and trefoil:

(*a*) Pivoted, non-gripping.
(*b*) Pivoted, gripping.
(*c*) Fixed, non-gripping.
(*d*) Fixed, gripping.

The range of cable supports available in the industry leaves much to be desired both in designs and types available, and in the author's opinion the development of economical ranges for all requirements is much needed. Two lengths for each diameter would provide for selection according to bearing pressure.

(9) THE MECHANICAL PROPERTIES OF LEAD AND ITS ALLOYS

Research has been undertaken to determine the relative merits of these materials in withstanding slow straining. Since accelerated tests could not be relied upon to give a true comparison, early results are not to be expected.

It seems probable that this characteristic is associated with modulus of elasticity and elastic limit, though the latter is known to be indefinite. The application of a constant strain, as distinct from stress, beyond the elastic limit causes the development of permanent set which may take some days to approximate to its asymptotic value. Since, in service, daily or more frequent cycles are involved, a low rate for this process should tend to long life. Any elastic limit of strain should also help.

A new and simple method of testing for modulus of elasticity and elastic limit has been devised which is specially suitable for these materials, and gives results of controlled accuracy much more quickly than by conventional methods. This consists in the use of a light beam, small-diameter pipe being convenient, suspended in a horizontal position by long cotton threads. This is bent by forces applied in a horizontal plane at the ends and middle, any effect of the weight of the sample being thus eliminated.

The modulus is found from the force and the deflection, and the elastic limit is given by the surface stress determined from the modulus and the maximum deflection without permanent set. The test is described in more detail in Section 11.4.

The values obtained for the modulus are in line with published figures, and confirm that the alloying of lead has little effect on this figure, but the tests for elastic limit show that it is much lower than hitherto published figures, if indeed any real value exists. The tests on alloys B and E were continued for 100 and 500 hours, respectively, and the elasticity was still diminishing. It follows that the modulus of elasticity is a transient value only.

The test results, taken at room temperature, are given in Table 3.

These values suggest that alloy B should be better than alloy E,

Table 3

Material	Modulus of elasticity	Elastic limit after 30 h	Elastic limit after 100 h	Elastic limit after 500 h
	lb/in²	lb/in²	lb/in²	lb/in²
Lead	$2\cdot6 \times 10^6$	1·0		
Alloy B . .	$2\cdot8 \times 10^6$	11·0	6·6	
Alloy E . .	$2\cdot5 \times 10^6$	3·4	2·0	1·5

which is known to be better than unalloyed lead, though the benefit would need to be substantial to offset its greater difficulty of working.

This test method is not so suitable for measuring the relation between creep rate and stress, since the stress is not uniform, but it is interesting to note that its sensitivity is such that, with a 50 in length of $\frac{1}{4}$ in-diameter pipe, a rate of creep of 1% in 40 years would be detectable in an hour.

(10) CABLE PROTECTIVE COVERINGS

Plain lead-sheathed cable may normally be placed on hooks either in or out of doors if protective coverings are not wanted for some special reason and the conductivity of wire armour is not required. Large quantities of such cable in iron hooks on the London Transport system have operated for many years without revealing trouble unavoidable with this construction.

Most users prefer to have some protective covering, and wire armour with bedding and serving is usual. Since this costs about $1\frac{1}{2}$ times as much as steel-tape armour and provides inferior protection against penetration by sharp objects, this preference is not easily accounted for where the ability to withstand tension is not required.

For cable on spaced supports the tension is small and is easily taken by the conductors, as is normal for single-core cables, and there is therefore a good case for the use of steel tape where any armour is wanted.

Protective coverings have, in general, been devised for withstanding burial in the ground. Without access of subsoil water the risk of sheath corrosion is virtually eliminated, and there would appear to be scope for coverings specially designed for exposure, with a minimum of bedding between sheath and armour, and concentration upon the weather-resisting properties of the serving.

(11) APPENDICES

(11.1) Assessment of Strain at Support

The maximum strain in a 2 in outer-diameter sheath, with 100 in span, is examined for behaviour as a beam and as a catenary.

(*a*) *Beam Formation.*

If L = Span.
Y = Deflection.
R = Minimum radius of curvature.
e = Fractional excess length of cable over span.

it has been shown in the earlier paper that

$$R = L^2/32Y = L/2\sqrt{(105e)}$$

and

$$e = 256Y^2/105L^2$$

Assuming an initial sag of 2%, initial $R = 100^2/32 \times 2 = 156$.

Initial $e = 256 \times 2^2/105 \times 100^2 = 0\cdot000975$.

After expansion, $e = 0\cdot000975 + 0\cdot0005 = 0\cdot001475$.

R after expansion $= 100/2\sqrt{(105 \times 0\cdot001475)} = 127$.

Strain due to expansion is $1/127 - 1/156 = 0\cdot00146$.

This will be decreased on the convex side and increased on the concave side by the amount the sheath is trying to expand minus the increase in length of the cable. A fair value for this would be that for 30° C sheath rise and 0·0005 cable expansion, giving $0\cdot0000293 \times 30 - 0\cdot0005 = 0\cdot00038$. The maximum strain then becomes $0\cdot00146 + 0\cdot00038 = 0\cdot00184$.

This is rather greater than the maximum repressed expansion in the sheath of a buried cable. Increasing the initial sag to 4%, for which the excess length is still under $\frac{1}{2}$%, reduces it to 0·0012 in, or about the mean repressed expansion.

(*b*) *Catenary Formation.*

The conditions for a proposed design may be checked as follows:

If we take a cable with a sheath of 2 in outer diameter and 0·1 in thick, of weight 1 lb/in, on a 50 ft span with 5% sag, the change in end slope is 0° 26′ = 0·007 57 rad and the tension is 1 800 lb. Let us assume a total maximum strain of 0·001 61, i.e. the maximum in the sheath of a buried cable. If 0·000 38 of this is due to repressed expansion as for beam formation, the amount caused by bending is 0·001 23. The radius of curvature to produce this is 1/·001 23 = 813 in. The length of arc for an angle of 0·007 57 rad is then 6·15 in, which is independent of the initial curvature. If the bending is limited to this length, the distance from the line of tension to the point of support would vary by 6·15 × 0·007 57 = 0·046 5 in or 0·023 3 in on each side of the mean position.

The resulting bending moment would be 1 800 × 0·023 3 = 42·0 in-lb. This would give a stress in the sheath of 155 lb/in^2, which would cause a quite negligible amount of strain during daily heat cycles. It follows that the bending must occupy a materially greater length than 6·15 in, and the strain will be correspondingly less.

(11.2) Geometry of Spans with Double Supports

If the pitch of the supports is L and the spacing of the supports of each pair is kL, then, by equating the slopes in each direction from a point of inflection, it is found that for an elastic beam the points of inflection, which come in a main span, are $L\sqrt{(1/3 - k^2)}$ apart.

The bending moment between the supports of a pair increases from the middle to each support in the ratio $(1 - 3k + 3k^2/2)$: $(1 - 3k + 3k^2)$, i.e. it is substantially constant. Nearly all the flexing at supports will therefore be nearly uniformly distributed over the length between the members of a pair.

The bending moment at the supports is less by the factor $1 - 3k + 3k^2$ than that with single supports at spacing L, or by $(1 - 3k + 3k^2)(1 + k)^2$ for single supports at $L - kL$.

It may also be shown that the ratio of maximum to mean bending moment is $3\sqrt{3}(1 - 3k + 3k^2)/2(1 - 3k^2)^{3/2}$. This is found to have a minimum value of 1·54 when $k = 0·284$, the value of k for the lowest curvature ratio. The ratios for $k = 0·1$ and 0·2 are 1·98 and 1·64, respectively.

The ratio of the deflection of the main span to the upward deflection of the short span is found to be

$$(1 - 10k^2 + 16k^3 - 7k^4)/(4k^2 - 12k^3 + 7k^4)$$

which, for $k = 0·284$, is 5·49.

(11.3) Experimental Comparison of Single and Double Supports

In order visually to compare the flexing due to expansion and contraction at single and double supports, two span lengths of alloy-E pipe, of $\frac{1}{4}$ in outer diameter and $\frac{1}{32}$ in thick, were erected with each construction.

For equivalent length in relation to stiffness, wL^3/I should have the same value for the same material. For the pipe this comes to $66L^3$, and for a representative cable (0·5 in^2 3-core 11 kV) about $2·25L^3$, taking I for the sheath only. Thus, in order to allow for conductors and armour, the span for the pipe should be a little under $\sqrt[3]{(2·25/66)}$, i.e. 0·32 times the cable span. A representative minimum cable span being about 100 in, the equivalent pipe span would be 32 in. It was convenient to adopt 50 in pitch, equivalent to about 13 ft for the cable, which clearly showed the features of interest, while being a fairly severe test.

The pair spacing was made 14·2 in, the optimum value. The effect of expansion was simulated by moving the supports, which were arranged to slide horizontally between adjustable limits. Since actual expansion would be only about 0·025 in in the 50 in, movements of 20 times this were applied, thus enabling the changes of shape in the region of the middle support (single or double) to be recorded on a card with a pencil guided by the pipe.

The pipe was first conditioned after erection by applying a 0·1% stretch. For double supports it was sagged 0·1 in in the main spans, giving an upward deflection of 0·18 in in the short spans. For single supports, an initial sag of 1·18 in was given for fair comparison.

(11.4) Modulus of Elasticity and Elastic Limit of Lead and its Alloys

The tests were made with extruded pipe of $\frac{1}{4}$ in outer diameter and $\frac{1}{32}$ or $\frac{1}{16}$ in thick. The test piece was a straight length of 52 in, and was suspended by five equally spaced cotton threads. Three vertical rods of $\frac{1}{4}$ in round iron for applying horizontal bending pressure were placed at 25 in intervals, the end ones being on one side of the test piece and the middle one on the other. The arrangement is shown diagrammatically in Fig. 5.

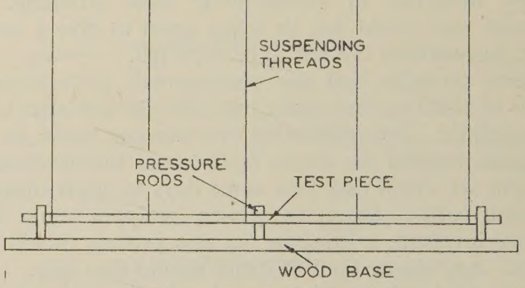


Fig. 5.—Arrangement of test piece for modulus of elasticity and elastic limit.

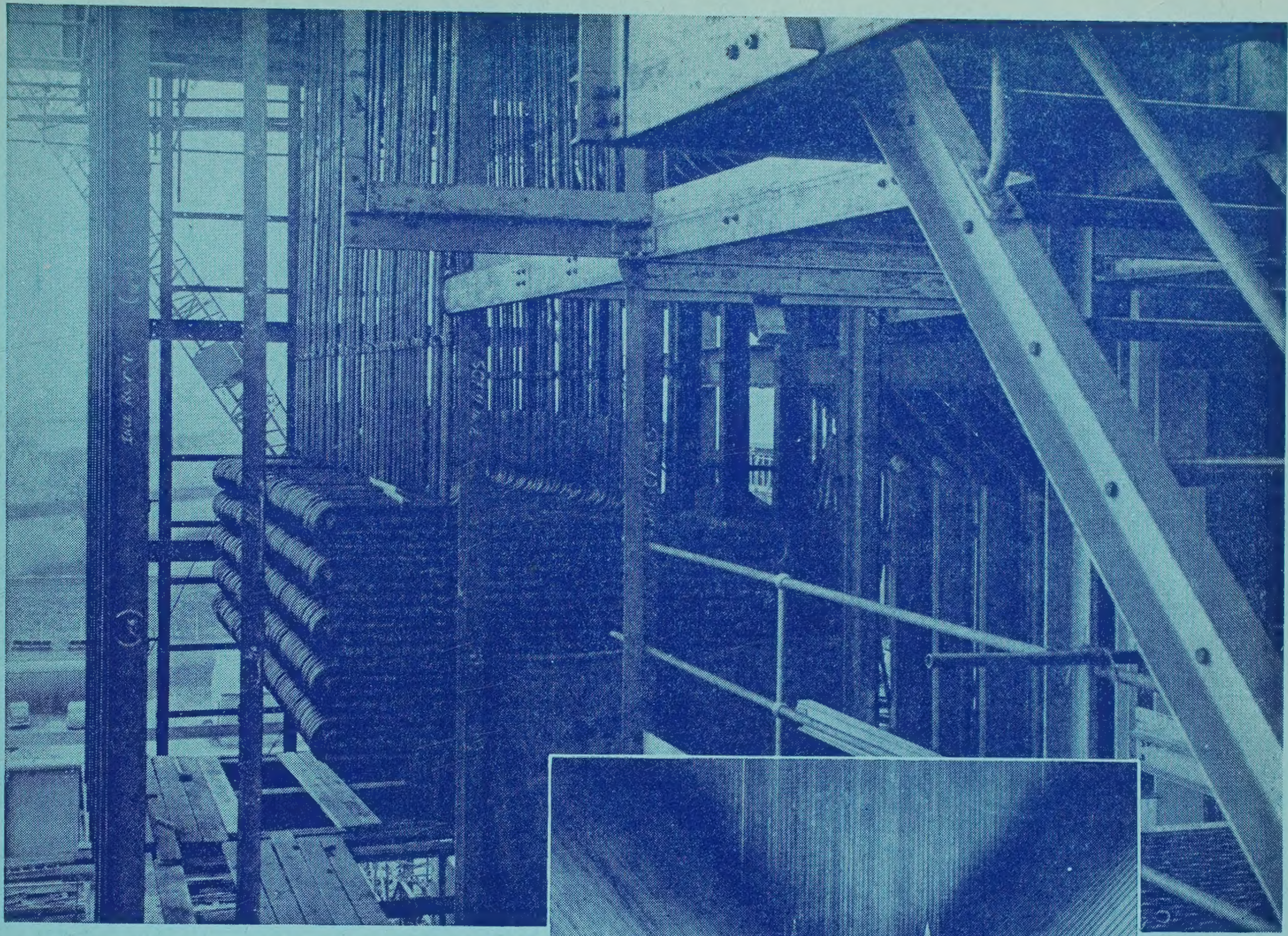
Other details, not shown for simplicity, are as follows: The pressure rod at one end was mounted in a frame so that it could be moved horizontally at right angles to the test piece by a 6 B.A. screw, play and backlash being eliminated by suitable means. The top end of each suspending thread was attached to a hook which could slide on a horizontal rod attached to the ceiling at right-angles to the test piece. From each of these rods was also suspended a plumb line for setting the adjacent suspending thread vertical.

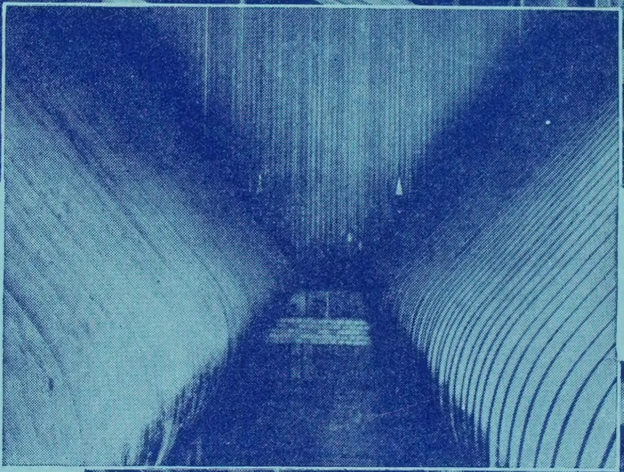
The test piece was held in contact with the middle and one end pressure rod by a light weight on a loop of cotton so that any relative movement took place at the rod at the other end. Each test piece was first set with a small clearance to the movable rod and left to stabilize until this remained constant for some hours.

For the modulus-of-elasticity test a horizontal pull was applied by a small weight on a thread over a light pulley to give a deflection which was measured by the number of turns of the screw to bring the rod into contact again, the reading being taken quickly to avoid permanent set, and checked on return.

For the elastic-limit test, a deflection of one turn of the screw, i.e. 0·021 in, was applied, and readings were taken at intervals of the amount the rod had to be drawn back to clear the test piece, the deflected position being immediately restored after each reading. In no case was this deflection sustained without permanent set. In the case of lead, after 30 hours only one-eighth of a turn was required to clear the test piece.

The true value of the elastic limit will tend to be even lower than that obtained, for the reason that elastic strain will remain in the region of the neutral plane, and will reduce the apparent permanent set.





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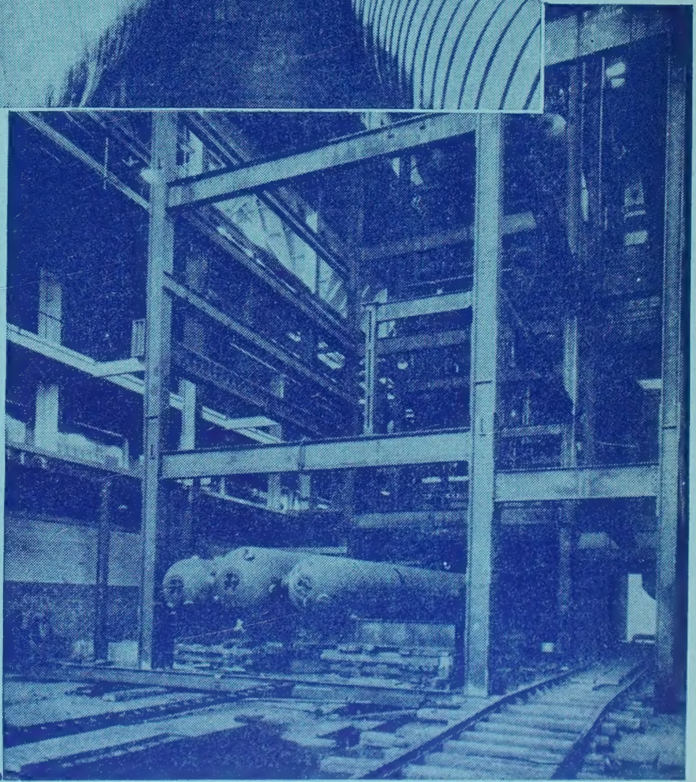

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PROCEEDINGS OF THE INSTITUTION OF ELECTRICAL ENGINEERS

Part A. POWER ENGINEERING, FEBRUARY 1958

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Published by The Institution, Savoy Place, London, W.C.2. *Telephone:* Temple Bar 7676. *Telegrams:* "Voltampere, Phone, London."
Printed by Unwin Brothers Limited, Woking and London.